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ADVANCED WASTE TREATMENT AND WATER REUSE SYMPOSIUM HELD AT ADOLPHUS HOTEL, DALLAS, TEXAS ON JANUARY 12-14, 1971. SESSION 1

Federal Water Quality Administration
Cincinnati, Ohio

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ADVANCE WASTE TREATMENT AND WATER REUSE SYMPOSIUM

Adolphus Hotel

Dallas, Texas

January 12-14, 1971

Sponsored By

Environmental Protection Agency

Co-sponsored By

Arkansas Pollution Control Commission
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Oklahoma Pollution Control Coordinating Board
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Advance Waste Treatment And

Water Reuse Symposium

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Tuesday, January 12

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Department of Water and Waste Treatment
City of Austin, Texas

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INTRODUCTION

by
Richard A. Vanderhoof

This Symposium on Advanced Waste Treatment and Water Reuse was organized by Region VI of the Environmental Protection Agency and the States of Texas, New Mexico, Arkansas, Louisiana and Oklahoma to promulgate the latest developments in waste treatment techniques. The program was planned to bring new information about wastewater treatment and water reuse to consultants, industrialists, and water pollution control authorities throughout the Region.

A variety of methods have been used to remove part of the pollutants from wastewater before it is discharged. In many situations, existing methods are not adequate to provide the degree of treatment required to control pollution effectively.

Research in waste treatment is being directed to development of methods ranging from lower-cost or higher-efficiency versions of conventional treatment technology to total wastewater purification systems capable of removing virtually all pollutants and of producing reusable effluents. The environmental Protection Agency's research in this area covers the entire field of waste treatment including treatment of industrial wastes, with special emphasis given to waste-treatment methods capable of total pollution control and purification.

OBJECTIVES OF THE SYMPOSIUM

F. M. Middleton

Water quality standards now in existence make demands on our treatment technology that have not been encountered in the past. Dwindling fresh water sources in many areas of the country have made it evident that renovation of wastewaters has a large role to play in supplying fresh water needs.

Recognizing that new and improved treatment technology would be required to restore used waters to a quality equal to the original water, the Advanced Waste-Treatment Research Program was started in 1960. Legislation over the past several years has provided support for greatly expanded research and demonstration programs in waste treatment. Much of this research has resulted in new and improved approaches to wastewater treatment. There is a natural lag in obtaining research results and putting them into technical practice. To shorten this time lag, this symposium and others like it are being presented to transfer the technology from the developers to the users.

The objectives of this symposium are:

1. To point out how advanced treatment and water reuse are vital in many of our cities.

2. To provide an understanding of the ways to measure, remove and control the nutrient elements in our wastewaters, particularly phosphorus and nitrogen. The approaches to this will be as follows:

    a. Describe the measurement and forms of phosphorus and nitrogen in wastewaters.

    b. Discussion of methods for removing phosphorus by use of conventional treatment and alum, lime, ion exchange, alumina and reverse osmosis.

    c. Report on the status of removing nitrogen by air stripping, ion exchange and biological nitrification-denitrification.

3. Improved removal of solids and BOD will be discussed from a variety of standpoints as follows:

    a. Oxygen aeration

    b. Application of physical-chemical processes such as coagulation, filtration, carbon adsorption, and reverse osmosis.

c. Progress in the treatment of small flow systems will be discussed.

4. The handling and disposal of sludges, slurries and brines will be considered.

5. Bacterial and viral aspects of wastewaters.

6. The role and progress in wastewater reuse particularly in the Southwest will be delineated.

ADVANCED WASTE TREATMENT AND WATER REUSE SYMPOSIUM
Tuesday - January 12, 1971

"WHY ADVANCED WASTE TREATMENT AND WATER REUSE IN THE MEGAPOLIS?"
--Henry J. Graeser

The "why" in the topic of my paper can really be answered by a few figures and in a few short words. Dallas has pursued a most aggressive program of water supply development since the early 1950's, having developed now four major reservoirs in the upper Trinity and Sabine watersheds. With the completion of these reservoirs a safe yield of nearly 360 million gallons per day has been developed, sufficient to carry Dallas County's expected population through the year 1995. Under planning is an additional reservoir on the upper Trinity which will extend available water resources to the year 2005. Planning studies are under way to look at available sources to the year 2020 and beyond. Evident in all of our projections is the fact that water costs are increasing both with distance and with inflation.

The Texas Water Plan, even with a reduced agricultural use, projects a water deficit of some 13 million acre feet per year by the year 2020. The deficit is in addition to a planned water reuse of some 8 million acre feet per year. This is quite pertinent and almost answers the topic question. The growing threat to the environment and depletion of pristine sources of water supply all testify to the imperative nature of the program in which you are engaged. Imperative as it is, however, other factors present themselves in this picture that must, of necessity, demand our primary attention. A recent article in Nations Cities listed the following data for growing water uses in terms of billion gallons per day:

In 1965 agriculture used	113 billion gallons per day
The 2020 projection is	166 bgd
Municipalities in 1965 used	24 billion gallons per day
The projection for 2020 is	74 bgd

Power generation in 1965 used	63 billion gallons per day
The 2020 projection is	414 bgd
Industry "self supplied" used	46 billion gallons per day
The 2020 projection is	211 bgd

Even with radical changes in America's life style with fewer and smaller automobiles, mass transit, better air conditioning, air pollution control and water resources planning which would involve reduction of return flows and water usage through thrift pricing and apartment dwelling, we face a formidable threat to both the environment and to the availability of water. Mr. George B. Maxey, Director for the Center of Water Resources Research in Reno, Nevada, said in the year 2000 the United States will have a population of 300,000,000 people. To provide jobs for these people and to maintain our standard of living will require 100% increase in mineral, fuel and power. He projected a 400% increase in water use by the year 2020. Economist, Robert Nathan, speaking at a national conference on public land policy and environment, using the same estimate of 300 million people in the United States by the year 2000 stated that "even if a law should be passed prohibiting women from having more than 2.11 children (the number to reach zero population growth), enough women are already born to assure a 275 million population by 2000."

The Texas Water Plan forecast a population of 30 million people for Texas in the year 2020. It is highly likely that Houston, Dallas, Fort Worth, and San Antonio can expect a lion's share of this population increase. It is fairly evident that appropriative water is a vanishing commodity. The future of any Texas city depends upon its developing and obtaining appropriative rights to meet this seemingly unavoidable future. These facts overshadow the interim problems of stream pollution. I use the term "interim" because the problems we now face in meeting stream standards based on recreational uses of our streams are obviously inadequate to speak to the question of a true water shortage. In an area such as Texas where an evident water deficiency exists, part of everyone's water future will be reuse of return flow. The criteria that we have customarily used

also pales into insignificance. Bacterial pollution becomes the easiest problem facing us and new criteria based on chemical content, heavy metals and organics will become the governing factors. Stream quality will be based on reusability rather than just recreational and ecological qualities. I can speak from experience that when you have no water, any water looks good. The question is - Can you drink it? - Can you use it?

Overshadowing our immediate problems of stream pollution is a growing competition for water. Agriculture, industry and municipal needs will vie for available supplies. Agriculture is facing this matter right now in that it cannot afford to pay the price for irrigation water which longer distances and pollution control place upon it. In any direction you look water reuse is in the picture. Furthermore, totally consumptive uses like agriculture have the cards stacked against them in double measure. Water used for municipalities and industry creates a hundred times the value in new product and in job opportunities than agriculture. In practical terms it simply means that industry and cities can out-bid agriculture for available water resources. Industry and domestic are non-consumative users. Too, as supplies grow and more and more of our population live in the urban areas, it is fairly evident that the needs of industry and the municipalities will be served. Big cities are helpless giants in the present situation. Their citizenry are, by and large, enthusiastic in supporting the environmental program. They have plenty of water, plenty of jobs, and plenty of money. But nearly any office holder will affirm that on an issue of wide personal interest, the urban population has the votes to swing the balance. On other issues they simply don't vote in proportion to the population. What I am saying is that if water becomes too expensive or, for that matter, pollution control becomes too expensive, if job security and standard of living are threatened because the environmental protection program has affected the ability of supplying fuel, fiber and power to a mushroomed population, the population can and will vote to reverse the trend even if it means loss of environment.

Now we have the interest and attention of the population in both water resources development and environmental protection. This is what we have been promoting for years. The problem is over-reaction and single mindedness. Our task, then, is to set a wise course. We are at a dawn or first light stage where esthetic barriers and interim standards prevent a realistic look at our goals. "Interim standards" I say because present standards are being set without consideration of economic facts of life. "Esthetic barriers" I say because as long as pristine supplies are available no one wants to consider reuse as either a present fact in part or a future in whole. But I simply have no doubt in my mind that the future we face is one which gives environmental control a sound economic base through reuse and reclamation of our water resources. The future will require acceptance of reasonable compromises in the use of our resources to maintain our population standard of living along with preservation to the maximum benefit. Recreation, relaxation and meditation all must accept tolerable compromises. We cannot preserve all the wilderness just to enjoy it if it is at the expense of the well being of the large majority. At the same time, we must plan our cities, rural, and wilderness environments so as to provide the maximum of pleasure and beauty, yet continue it as a land of opportunity. Let us keep in mind that scarcity enhances rather than depreciates value. I remember vividly a small but beautifully designed park in New York City which nestled in the midst of crowded city streets and skyscrapers. The increased attention given to pedestrian malls, expenditure for landscaping and greenery in downtown city areas can bring an entirely different aspect to city living.

So, "why advanced waste treatment and water reuse?" - simply because we have about 20 years to gain the knowledge that we need to implement it safely. Our water pollution control program should be directed at the obviously ultimate goal rather than stopping short with a pleasing stream dedicated to recreation. In every instance the water is an essential economic commodity which is going to have to be used again and again if we are to maintain our nation's prosperity. Our research and our construction efforts

have all stopped short of this ultimate goal, not from any lack of desire on the part of the federal and state agencies involved, but limited as always by funds and organizational responsibilities. The water we drink is quite different from the water we can play and fish in. While the dollars which have been spent in research seeking better methods for water pollution control will certainly have their impact in solving the ultimate problem of the water we drink, it has suffered by its inability to address the ultimate goal rather than the interim solution. The re-formation of the environmental agencies into a single agency is a step in the right direction in that now the Environmental Protection Agency can address itself to the whole problem as I am sure it has wished to do in the past. Likewise, the Bureau of Water Hygiene which has been restrained by a complete drouth in funds for research in drinking water will hopefully be funded and staffed in such a manner as to supplement the effort needed to meet the whole problem.

Consider the effect of a water utilization program wnere we could utilize return flow in the total water budget for an area. The regional plan for the North Central Texas Council of Governments envisioned five or six watershed systems. These six include two area sewage treatment plants below Dallas and a central sewage treatment plant on the East Fork below Lake Ray Hubbard and an extension of the TRA central interceptor system reaching all the way to Lewisville on the Elm Fork. If return flow were of such a quality that it could be considered part of the area water resources, discharges of drinking water quality could be returned to water reservoirs utilizing the dilution available and at the same time increasing the safe yield of these reservoir facilities. The savings in interceptor costs to divert waste water flows below impounding reservoirs would be saved, and these are some of the biggest expenses involved. Likewise, even though waste water treatment costs would increase several times, probably in the vicinity of 15¢ or 16¢, this is approximately what imported water from 100 miles away will cost. Thus, if a 100 million gallons of water were

returned to the water sources of just the Dallas area, the savings in water supply development and importation would amount to $5,475,000.00 a year at 15¢ a thousand. This can be considered a savings only when you compare it to the present practice of returning flows to the streams for discharge to the gulf and admit stream standards will eventually dictate tertiary treatment on the Trinity River. The proposition whereby such water would be returned to reservoirs with dilution will also eliminate many of the stringent requirements in quality control which is implicit to direct reuse because a time lag is available for normal analytic tests for toxic concentrations which would be dangerous to the public health either for recreation or drinking water. The only problem, then, for this first step is purely esthetic.

It is interesting, too, that in such a scheme water which would have to be pumped to the reservoirs from waste water treatment plants below the impoundments could be scheduled only during periods of drouth when reservoirs fail to recharge from natural runoff. If we could only accept, then, the idea of reusing water, you are given an economic reason for very high degrees of more expensive treatment processes which would produce a drinking water quality into the streams. Other possibilities offer themselves, too, in that during flood periods or flood discharges from reservoirs a savings in treatment costs could be effected by eliminating some of the tertiary processes and at the same time eliminate the cost of pumping to storage. Under these conditions the normal 20 ppm B.O.D. would be more than adequate since the dosage of nutrients and pollutants both would be dispersed and intermittant. So, immediately before us is the economic incentive to tertiary treatment. The only barrier lies in improved technology to reduce the costs, improved process control and public acceptance.

In conclusion, let me simply mention some of the more obvious areas where we are deficient if we are to consider direct reuse. Primarily our technology for secondary and tertiary treatment of waste waters is still deficient despite the very fruitful research we have been prosecuting. There is a huge cost jump between conventional

activated sludge or trickling filters to alternate methods of treatment. Despite all our research we still have not found more efficient processes at lower cost. Chemical and mechanical methods of purification create additional disposal problems. The biological process still reigns in attacking the problems of dissolved pollutants in waste water. Above all, we do not have the key to what makes the process work in all instances. This means we can't control the process or design it efficiently for all possible conditions. To put an economic base under water pollution control through water reclamation, we are faced with a degree of quality control never before considered necessary in waste water treatment plants. We are faced with a degree of control of what goes into the sewer never before considered necessary. Compounding this problem is a continued and increasing investment in plant facilities and collection system which we know with increasing uneasiness will not be adequate to the task before us and cannot be rectified readily because of the financial burden involved. We are committing our resources in many instances to inadequate solutions and these resources are indeed limited. We are going to have to come up with analytical controls that are "fail safe" if water is to be reused. We are going to have to stop overwhelming the problem with surplus capacity and begin to think in maximum utilization through process control coupled to reliable on-line instrumentation which will detect those parameters which affect treatment efficiency and the safety of the end product. As a minimum we are going to have to immediately initiate higher standards of house plumbing, house building sewers and collection system materials and workmanship. There must be radical changes in design and repair methods of collection systems to insure that these facilities exclude the entrance of extraneous flows which overwhelm and depreciate the efficiency of treatment processes. We must begin the almost financially impossible task of rebuilding the collection systems of our cities in such a manner as to exclude storm water infiltration. We must greatly expand and implement an industrial waste surveillance and control which will extend even to the household through exclusion of products which are dangerous to the ultimate goal of water reclamation and reuse.

But above all, we must keep our eye on the ultimate objective and that is reuse not just stream pollution control. We must and can grapple with the problems of the environment. We must address ourselves to the population problem and the increasing tendency of these new people to urbanize. We must solve the in-city environment problem if we are to live in the megapolis and that environment must be one which includes functional beauty in such a way as to inspire its citizens to perform efficiently and live constructively. We must think in terms of human benefits which are both economic and philosophical, because both are involved in our choice of priorities. We must not let pollution become a smoke screen to distract us from more immediate and essential challenges to mankind. It is a demanding part of the challenge - but it finds its solution through broader challenges essential to our well being and survival. The water we drink is one of those basic human needs.

League of Women Voters of the U.S.
1730 M Street, N.W.
Washington, D.C. 20036

January 12, 1971

GAINING PUBLIC ACCEPTANCE OF WASTE WATER REUSE

by
Mrs. Jessie Rudnick
Committee on Environmental Program and Projects
League of Women Voters of the United States

at the
Advanced Waste Treatment and Water Reuse Symposium
Federal Water Quality Administration
and Texas, Oklahoma, Louisiana, New Mexico and Arkansas
Dallas, Texas
January 12, 1971

I want to say that I am delighted to have this opportunity to talk to you about waste water reuse because you are the professionals, the ones who can answer the questions the public is likely to ask about waste water reuse. You are the ones who will want to bring the answers to the attention of the public so that we can get on with the job of cleaning up our nation's water resources in order to make the best and fullest use of them.

The League of Women Voters has taken a strong position in favor of improvement in water quality. We have supported full authorized federal funding for sewage treatment plant construction, taking an active part in the Citizens Crusade for Clean Water which won an appropriation of $800 million for fiscal 1970 and $1 billion for fiscal 1971. We hope some of this money will be used to provide advanced waste water treatment, making use of techniques which have been developed in pilot plant and laboratory studies sponsored by the Federal Water Quality Administration.

To me this is an exciting prospect. I believe that the use of reclaimed water, even in the potable water supply, will be the "in" thing only a few years from now. Who doesn't want to be in the forefront of progress? Those of you who are planning now for waste water treatment facilities which will produce effluent of drinking water quality will be the heroes of your communities very soon - yes, even if it does cost more. I can hear it now: "My community is a better place to live than yours because we treat our sewage so thoroughly that we can even drink the effluent." "We don't pollute our river. It's safe to swim in." "Our children have a wonderful time at the city pool in the summer. It takes water right from the sewage disposal plant." "Our factories have cleaned up too. And, do you know, they've found that it doesn't cost any more to recover the minerals than to dump them into the river?"

There are two basic reasons why I make this prediction. One is that we are rapidly finding out, even in relatively well watered areas, that our supply of fresh unpolluted water is not inexhaustible. Another reason is that we can no longer contemplate disposing of our wastes indefinitely by just dumping them into the nearest body of water. The concept of the closed system, with all wastes

reclaimed as much as possible and only makeup water added, is one we can and must achieve if we are to save our environment.

In preparing for this occasion, I asked several of my friends how they would react if they were told that from now on reclaimed sewage effluent would be returned to the city water system. The reply was either a stunned silence or a grimaced "ugh." However, in every case, after this first startled reaction, a further discussion revealed that the person I talked to would be quite willing to accept such an action, provided he could be convinced that the effluent had been treated in such a way that it was safe to drink. Therefore, I want to talk to you today about some of the questions I believe people will want you to answer when you present to your community proposals for waste water reuse.

I feel sure the first question will be: "Is it really possible to clean up our sewage so that the effluent will be safe to drink?" The answer, as you know, is: "Yes, the technology has been developed to do just that." However, I say this with some reservations because even though we have pilot plants which can produce potable water from domestic waste water, there still is, to my knowledge, no full scale system in operation in this country which actually returns potable water directly to the water supply system. Other countries are reusing waste water successfully. For example, the city of Windhoek, in Southwest Africa, a water short area, has a sewage treatment system which provides about one third of the total potable water for the city water supply.

The Summary Report - Advanced Waste Treatment - July, 1964-July, 1967 issued in 1968 by the Federal Water Quality Administration, then the Federal Water Pollution Control Administration, makes surprisingly interesting lay reading, at least to those of us who are concerned about the deterioration of our water quality. We've learned that every stage of advanced treatment of domestic sewage has been tested experimentally in this country and that there are several different ways of achieving an effluent of drinking water quality which may be tailored to the quality of the raw sewage. There are pilot plants in Lebanon, Ohio; in Pomona, California; and in Washington, D.C., where new methods of treatment are being developed. In addition, there are many other places where advanced methods of waste water treatment are being tested. In every case, though, the system stops short of returning the effluent directly to the potable water supply.

The Whittier Narrows plant in California recharges an aquifer. The Pomona, California plant effluent is used for irrigation. Effluent from the South Lake Tahoe water reclamation plant is piped over a ridge to a new man-made recreational lake. The Lake Tahoe effluent meets USPHS drinking water standards, yet it is not returned to the lake. Why? What keeps us from taking that logical next step of reusing the water directly? There appears to be a widespread belief that the public will not accept such a step. I believe that the public will accept such a step when given the right information. I hope that soon the effluent from many pilot and experimental installations in this country will be returned to the potable water supply. And when this does happen, I hope the event will be widely publicized so that many people will hear of it. I hope any of you who are there will be glad to publicly drink a glass of water from one of the advanced treatment plants so that everyone will see that it is drinkable. Actually, you may find that the water tastes flat because it lacks some of the contaminants you are used to.

In order to combat unfavorable rumors and untruths, the public needs basic information. Admittedly it may not be easy to explain some of the more sophisticated water treatment processes to the general public but I believe the public would certainly like to know what can be accomplished. For example, one can hardly pick up a newspaper or magazine today without seeing a reference to the damaging effects of excessive amounts of phosphates in waste water but few people seem to know that the phosphates can be removed from the waste water. As with the foam from non-biodegradable detergents, the solution to excessive phosphates may lie in changing the composition of detergents but I'm sure the public would like to know what alternatives are available.

The League of Women Voters believes that the cost of cleaning up industrial waste water should be considered a cost of doing business, although limited federal assistance may be necessary in some cases at the beginning. We should not like to see the possibility of waste water reuse jeopardized because of industrial contaminants. We hope that the job of cleaning up our water supplies will not be slowed down because domestic and industrial wastes have been combined in the past.

Once the public is convinced that waste water reuse is technologically feasible, or possibly even before, the second question will be raised. "Do we really need to go to the trouble and expense of recycling our waste water?" Again I believe the answer is "Yes," and again the reasons are the same. We are running out of new supplies and we shouldn't be allowed to dump our wastes into what may be someone else's water supply. I think a fairly large segment of the public is already concerned about the deteriorating quality of our water supplies in many places and I am also sure it is apparent to some people that we are already recycling our water. As communities grow in size and number, it becomes increasingly unlikely that the waste water from the town upstream will have purified itself by the time it reaches the fresh water intake of the town downstream. If the water comes from wells, we are finding that often the supply will not meet the increasing demands. New wells may be drilled but the underground supply is not inexhaustible.

The question is, "At what point do we decide that the water in our fresh water source is no better than the water from our waste treatment plant?" Hopefully we will be giving advanced treatment to our sewage and recycling it before that point is reached. Some of the advanced waste treatment techniques are identical with those used to purify intake water; lime coagulation and sedimentation, for example. There should be some possibilities here for an integrated system.

In a wry sort of way our prodigality may be our salvation. We've been so prodigal about throwing away our used water that we have quite a lot to salvage. Many coastal cities have been dumping their waste water into the ocean, often with little treatment. Even in well watered areas this amount of clean water would make a significant addition to the city water supplies.

It is becoming increasingly hard to find adequate sources of new fresh water in the west especially. Expensive water transport systems may have to be built to provide the water needed if we do not turn to recycling. Alternatively we may need to curtail agricultural use of water in order to provide industrial and domestic supplies if we do not recycle the water.

When we are faced with decisions like these, we come to the third question which will be asked by the public. "Is it economically feasible to recycle our waste water?" The cost of tertiary treatment facilities will be high, possibly as much as three times that of providing secondary treatment. Since we have fallen behind in so many places in providing even adequate secondary treatment, the cost of providing treatment which will enable cities to recycle their water will indeed be high. However, we are already paying a high price for pollution in our rivers, oceans and lakes. This is a price we pay in disease, in loss of recreation, in the loss of both commercial and recreational fishing opportunities, and in loss of property values. We must balance these costs against the costs of cleaning up the water.

Balancing these direct and indirect costs against the cost of tertiary treatment may easily result in a balance in favor of reuse. Even the cost of one new well may be more than the cost of recycling an equivalent amount of water.

The city of Santee, California found that it was cheaper to give tertiary treatment to its sewage than to build a new sewage treatment plant. In addition, it reaped the indirect benefits in water-oriented recreation. Downstream users find the treated water preferable to water which comes from the Colorado River in open aqueducts because it has fewer dissolved salts.

The use of bottled water is increasing in this country, primarily because of deteriorating quality of water supplies. This is certainly an expense people would prefer not to have.

This, then, is the information I think people want before they can be convinced that waste water should be recycled. They want to know that it is possible to clean up waste water so that it can be recycled. They want to know that it is necessary to do so, and they want to know that it may be cheaper to do so, when all expenses have been considered.

There still remains the question of how to get started. An astonishing number of people still don't really care where their water comes from or where it goes after use, as long as it is free from objectionable odor, taste or appearance when it arrives and as long as it disappears after use. How do we persuade the public to ask the questions I have discussed? I think the initiative should come from you. This is because you know the needs and the possible solutions, but I hope you will enlist the aid and support of concerned citizens groups such as the League of Women Voters, local conservation coordinating organizations and the Izaak Walton League.

Let us suppose you have surveyed the needs of your own community and have prepared a plan for water reuse. You send a copy to the president of the local League of Women Voters. The League water resources chairman reads it, decides that it is within the scope of its program and prepares to investigate the plan in order to present it to the membership for their opinion and perhaps approval. The League member will need background so she will ask questions. She will want to know where the city water supply comes from, why it will not be adequate for future expansion, what its quality is at present, how it is treated before use. She will want to know what happens to the water after it is used, how adequate are the sewage disposal plants, both in number and in quality of treatment. She will want to know costs, the cost of present supply and disposal and the projected costs. She will want to know whether our environment is being adequately protected now and whether the proposal will also protect the environment.

I hope you will tell it as it is, even if your town has fallen behind and is not meeting present standards of good treatment. Once League members have the facts and have reached consensus, they will help you alert the public and put pressure on the proper public officials. When all this has been done, I am sure the concept of waste water recycling will be readily accepted.

Together we should be able to achieve the support for waste water reuse which will be so important in the years to come. I hope that within my lifetime I shall see a real change from the present increasing pollution of our water supplies to rapidly decreasing pollution, with all the benefits to life on this planet that such a change implies.

MINERAL REMOVAL BY ION EXCHANGE, REVERSE OSMOSIS AND ELECTRODIALYSIS

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Introduction

The purpose of this paper is not to argue whether or not demineralization of wastewater will some day be practiced, but to review some relevant research findings and cost estimates which may influence when and where such demineralization will occur. There are, of course, large quantities of wastewater in California with dissolved solids concentrations well above what might generally be conceded as acceptable limits. Such waters will probably not be reused unless they have been demineralized. However, there are many more situations in which wastewaters have marginal dissolved solids concentrations of slightly above or below 1,000 mg/l. In discussing waters of this quality with water supply agencies there appears to be considerable interest in reducing the dissolved solids to more desirable levels. This situation, which can be described as removing the increment of dissolved solids added to the initial water supply by one-time use in the community, seems to be the most probable application for demineralization in the near future, and most of the research work and cost estimates contained in this paper have been developed on that assumption.

The Sanitation Districts have been involved in pilot scale evaluations of demineralization processes since 1965. The work has been conducted jointly with the Federal Water Quality Administration at the Sanitation Districts' Pomona Water Renovation Plant. A portion of the 10 mgd activated sludge plant effluent is diverted to the Research and Development Facility shown in Figure 1. In addition to the various pilot plants, the research facility includes office and laboratory space for five engineers and seven chemists working on various studies. At the heart of this research facility is a 300,000 gallon per day, four-stage, downflow, packed-bed, granular activated carbon adsorption column. For the past five years this system has received typical secondary effluent from the Pomona plant and reliably produced a high quality carbon filtered water which has also served as the feed water for the demineralization processes. Average quality data for the activated sludge plant effluent and carbon adsorption product water are shown in Table 1.

Since all of the demineralization processes investigated at Pomona involve membranes or resins which are subject to fouling in the presence of high concentrations of organic matter, activated carbon adsorption is at present considered an integral part of these demineralization schemes.

Presented at the Workshop on Wastewater and Reuse sponsored by the University of California, Berkeley, held at South Lake Tahoe, Calif. June 25-26, 1970.

The cost of activated carbon treatment is estimated at 9¢ per thousand gallons for a 10 mgd facility, which must be added to the demineralization cost to arrive at the total cost estimates for each of the three processes presented at the end of this paper. The three processes -- reverse osmosis, electrodialysis, and ion exchange -- are presented in decreasing order of total estimated cost based on the studies to date.

Reverse Osmosis

Although the reverse osmosis process is the newest technological development of the three processes studied at Pomona, it was the first to be piloted there. There are many ways in which the principals of reverse osmosis can be converted to hardware and there are at least five or six companies with different versions of the process. Three of these have been piloted at Pomona but only two have been operated for sufficient length of time to permit a reasonable evaluation of their performance and economic potential. In the foreground of Figure 2 there is a 12,000 gallon per day unit manufactured by the Gulf General Atomic Corporation, and on the left edge of the slab a 3,600 gallon per day unit manufactured by Universal Water Corporation.

The Gulf General Atomic (GGA) unit features a spiral wound membrane packed into high pressure, 4" diameter pipes arranged in series. The configuration of the membrane module is illustrated in Figure 3. Each module is comprised of a wound up sandwich comprised of two layers of membrane for the "bread" around a "filling" of membrane support material. A brine side spacer separates layers of membrane as the membrane is wound around a low pressure product water tube at the central core. The brine stream passes longitudinally down the membrane through the spacer under an initial pressure of 465 psi. Water molecules pass through the membrane and travel spirally through the backing material to the low pressure product water collection tube at the center. Each module is 3' long and contains 50 square feet of membrane surface area. The unit shown in Figure 3 has a total surface area of 1,350 square feet and a flux rate of slightly under 10 gallons per day per square foot.

The Universal Water Corporation (UWC) unit features a more typical reverse osmosis design. The basic component of this system is a half-inch diameter perforated plastic tube which serves as the support for the membrane which is contained within the tube. Eighteen of these tubes are connected in series and housed within a 4" diameter product water collection pipe. The feed water flows through each tube at an initial pressure of 600 psi. The 4" diameter modules are connected in a combination of series and parallel arrangements to achieve the desired flow rate past each membrane. This unit contains 225 square feet of membrane area and has a flux rate of approximately 15 gallons per day per square foot, which is substantially greater than that of the GGA unit, even when accounting for the difference in operating pressure.

Although the present state of development of the reverse osmosis process results in the highest cost estimate of the three processes considered at Pomona, it is also the process with the greatest potential

for technological improvement. Significant improvements in either flux rate or membrane life could appreciably lower cost estimates. In order to provide reasonably reliable estimates for the present state of technology, the Sanitation Districts are operating both the GGA and UWC units on extended runs to determine the life of the membranes and the rate of change in flux rate with time. The performance of the two units is compared in Figure 4. At this time the GGA unit has been onstream about 9,000 hours, or approximately one year, compared to about 5,000 hours, or seven months, for the UWC unit. These runs are believed to be the longest continuous runs of a reverse osmosis system for the demineralization of reclaimed water. Even so, it will require another year of operation of the GGA unit to confirm the two-year life expectancy which has been assumed for purposes of the cost estimate on this process.

The difference in flux rate between the two units is substantial and apparently represents a difference in the state of technological development of membrane production by the two companies. The rate of decline in flux rate has been identical for each unit and has been empirically found to follow a straight line when plotted against time on a log-log scale, as shown in Figure 4. During the course of the life run the influent water has been automatically maintained at a pH of 5 with sulfuric acid. There is a daily flush with a mixture of air and tap water and a weekly flushing with an enzyme detergent. Whether these routine operating procedures must be increased or can be reduced without affecting membrane life still needs to be determined.

Data on performance of the GGA unit is presented in Table 2. Average water recovery during this period was 75%, although it is anticipated that for a large installation a more advantageous flow pattern would permit recoveries of up to 85 percent. Because of the general interest in nutrient removal, Table 2 includes data on ammonia nitrogen, nitrate nitrogen and phosphate, as well as on TDS. It should be noted, however, that when these processes are used to remove the increment of TDS added during one municipal use of water, nutrient levels will not be reduced sufficiently to inhibit eutrophication problems. This process has maintained over 90% TDS reduction for an extended period and has the advantage of similarly high removal of COD materials. It is even more selective for the removal of phosphate but has only achieved about a 50% removal of nitrate nitrogen.

Electrodialysis

The 15,000 gallon per day electrodialysis unit constructed by Ionic Inc. is shown in Figure 5. A rectifier in the gray chamber in the foreground provides a 70 volt DC output across the membrane stack, just visible on the left. The membrane stack is 18" x 20" x 12" deep and contains 65 anion and cation permeable membrane pairs and their respective spacers. The flow diagram is illustrated in Figure 6. A flow of approximately 12 gallons per minute in the feed stream is split with 10 or 11 gallons per minute passing through the dilute stream and becoming product water as the cations and anions migrate into the concentrate stream. The remaining one

to two gallons per minute of the feed stream is mixed with 10 to 11 gallons per minute of brine recirculation flow to provide equal flow rates and consequently equal pressures on both sides of the membranes. A pH of 3.5 in the concentrate stream is maintained automatically by the injection of sulfuric acid.

The percent conductivity removal during the first three months of operation of this unit is presented in Figure 7. Decreases in percent conductivity removal are closely related to decreases in amperage across the unit. The unit is designed to operate at 4 amps and generally achieves a dissolved solids reduction of about 34 percent. On the average, conductivity removal has been relatively stable. Most of the fluctuations noted on the graph are related to the changing character of the TDS of the water rather than to changes in the membrane itself. Routine operating procedures to maintain high performance include flushing with a sequence of an enzyme detergent, tap water, and acid every second day with the voltage shut off. This has permitted at least four months of operation without requiring manual cleaning of the membranes. The relative cost of more frequent manual cleaning vs. routine flushing has not yet been determined. Performance data from a previous period of operation is shown in Table 3. The process is more selective for nitrogen compounds and less selective for phosphate than for average TDS removal. This process has the disadvantage of being relatively ineffective on soluble organic material, as represented by the 15% removal of COD.

Ion Exchange

The ion exchange pilot plant shown in Figure 8 was originally supplied by Infilco Corporation with its own pretreatment unit. However, the pretreatment unit was unreliable and the cost of pretreatment was greater than the savings in ion exchange costs, which resulted in abandonment of the pretreatment portion and operation of the ion exchangers with carbon filtered water. A simplified flow diagram is presented in Figure 9 for this strong acid-weak base ion exchange process. The unit operates at 2.5 gallons per minute for a 16-hour period each day and produces about 2,400 gallons of product water per day. The primary cation exchanger contains 8 cubic feet of resin and the secondary cation exchanger 3.2 feet of resin, with each of the anion exchangers containing 1.6 cubic feet of resin. Once a day the last three exchangers are shut off and the primary cation exchanger is backwashed with feed water. Once a week each of the other exchangers is shut off in sequence and backwashed with its normal feed water.

A simplified diagram of the regeneration process is presented in Figure 10. Sulfuric acid is used to regenerate the cation resins and ammonium hydroxide is used to regenerate the anion resins. The regenerates are discharged to waste and the resins are given a product water rinse.

Comparison of the feed and product water TDS for 80 days of operation is presented in Figure 11. The influent TDS averaged slightly over 600 mg/l, and the product water TDS averaged about 70 mg/l. Ion exchange systems are generally used in industry to produce extremely low concentrations of dissolved solids. For demineralization of reclaimed water, however,

substantially higher TDS values are not only permissible but desired to reduce costs. By reducing the degree of regeneration of the resins and operating beyond the normal breakthrough point for industrial water quality, it has been possible to reduce the cost of regenerating the resins while producing a very acceptable demineralized product water.

By manipulating the end points, as previously described, the ion exchange system has accomplished an average TDS reduction of 87% at an average water recovery of 87%, as shown in Table 4. COD removal was much better than expected in this process and phosphate removal is outstanding, although this ion exchange system is less selective for ammonia nitrogen.

Cost Comparison

Tables 5, 6 and 7 present comparative cost estimates for the reverse osmosis, electrodialysis and ion exchange processes based on producing 10 million gallons per day of product water. The reverse osmosis estimate in Table 5 still involves many assumptions. First, the capital cost has been provided by the Gulf General Atomic Corporation and is believed to be conservative, but until plants of this type are constructed on a large scale, reliable production costs will not be available. The cost of chemicals is surprisingly high in this estimate and is largely represented by the cost of pH adjustment and enzyme detergent flushing. There may be some possibility of reducing this cost in the future. The item for "maintenance materials" is figured at 5% of the depreciable portion of the capital investment on all estimates and is a relatively minor portion of the total cost. Power is naturally a substantial figure for a reverse osmosis system and cannot be reduced. The largest item is membrane replacement which is one of the reasons membrane life and flux rate are the points where major emphasis on improving technology must be placed. The effect of changing either of these variables is illustrated in Figure 12. A two-year life and 10 gallons per day per square foot flux rate has been used in the previous cost estimate. Accomplishment of a three-year membrane life and an increase of flux rate to between 15 and 20 gallons per day per square foot would make a 1/3 reduction in the total cost of this process.

At first glance the estimate for electrodialysis in Table 6 looks relatively low. However, this cost, as opposed to that of reverse osmosis and ion exchange, does not have the potential of being reduced by blending since the process only achieves about a 1/3 reduction in TDS. Furthermore, it is felt that the capital cost of the process as well as the operating cost are relatively well known, with only minor possibilities of making slight improvements in either chemical usage or labor costs in the future.

The cost of ion exchange, as presented in Table 7, appears to be the most reliable estimate of the three processes, although the cost of regenerants is related to the particular combination of ions included in the overall dissolved solids of the feed water. Furthermore, this process

is the most sensitive to waters of variable or high dissolved solids content because the cost of regenerants is directly related to the number of ions removed. With regeneration costs amounting to 16.2¢ per thousand gallons out of the total estimated cost of 22¢ per thousand gallons, it is apparent why most of the effort has centered on improving the efficiency of utilization of regenerants. Resin replacement is not a particularly large cost item, although the 20% per year figure is considered somewhat conservative.

In Figure 13 the total cost of the three processes are compared under equivalent conditions for an influent TDS range from 500 to 1,500 mg/l. In each case it has been assumed the influent TDS is reduced by 33% through demineralization. For the electrodialysis unit 33% is approximately the reduction obtained in a single pass. However, both the reverse osmosis and ion exchange units provide 90% TDS removal, hence the cost of these processes have been adjusted by assuming a mixture of demineralized and non-demineralized carbon effluent to produce 20 mgd of the desired TDS product concentration. Though these stimates include the 9¢ per thousand gallons cost of carbon filtration, they do not include the cost of brine disposal. On the coastal plain of Los Angeles County, brine disposal is not a problem since brines can be returned to the sewerage system and ultimately reach the Pacific Ocean. For inland plants this problem would be of such major proportions as to essentially eliminate consideration of demineralization of reclaimed wastewaters in such locations. Throughout the range of TDS considered, the ion exchange process remains the most economical and amounts to about 20¢ per thousand gallons for a 33% TDS reduction for an influent TDS of 1,000 mg/l. The ion exchange cost curves have therefore been the basis for the generalized cost curves presented in Figures 14 and 15.

Figure 14 shows the estimated cost to obtain a particular product water TDS for a range of influent TDS values up to 1,500 mg/l. Figure 15 shows the estimated cost of achieving a selected amount of TDS removal for the same influent TDS range. These costs include pretreatment by carbon adsorption and exclude the cost of brine disposal. The horizontal plots in Figure 15 illustrate the nature of the ion exchange process since the cost of the process is essentially proportional to the ions removed or exchanged, regardless of the influent TDS. All of the previous estimates have been based on the cost of a 10 mgd demineralization facility. An estimate for a 10 mgd facility is obviously quite an extrapolation from the 2,000 to 15,000 gallons per day pilot plant units which have actually been tested. In Figure 16 the costs of achieving several different product water TDS concentrations with an influent TDS of 1,000 mg/l have been estimated for plant sizes from 0.5 to 10 mgd based on the ion exchange process. It appears that extremely small plant sizes will remain uneconomical but that there may be possibilities for minor improvements in cost for plants larger than 10 mgd. A recent article in the Journal of the American Water Works Association by William R. Gianelli (April, 1970) includes an estimate of 37¢ per thousand gallons for desalting sea water in a 50 mgd plant combined with a large nuclear power generating facility. With no knowledge of what assumptions were actually used in the estimate, it is of interest to note that it is quite comparable to the cost of reducing the TDS in 10 mgd of secondary effluent from 1,000 mg/l to about 500 mg/l obtained from Figure 16.

Summary

The strong acid-weak base ion exchange process piloted at Pomona has proven to be more economical and reliable than the reverse osmosis or electrodialysis systems with which it has been compared. Practical reductions in dissolved solids can be obtained for costs of 20 to 30 cents per thousand gallons where brines can be discharged to the ocean. These costs should be confirmed by construction of a larger pilot facility but indicate that reclamation, demineralization and reuse of wastewater should be considered prior to demineralization of seawater and carefully compared with the estimated costs of future imported supplies.

Credits

The research work reported upon in this paper was jointly financed by the Federal Water Quality Administration and the Sanitation Districts of Los Angeles County. The following project engineers from both agencies have operated the pilot units, collected and analyzed data, and overcame numerous problems in developing the information upon which this paper is based:

Project Engineers	Process
Max Augustus	Reverse Osmosis
Robert Miele	Reverse Osmosis
James Gratteau	Reverse Osmosis
John English	Electrodialysis
John Burgeson	Electrodialysis
Harold Takenaka	Electrodialysis
Hans Krock	Ion Exchange
Ching-lin Chen	Ion Exchange

25<

PHOTOGRAPH NOT INCLUDED

FIG. 1: POMONA RESEARCH & DEVELOPMENT FACILITY

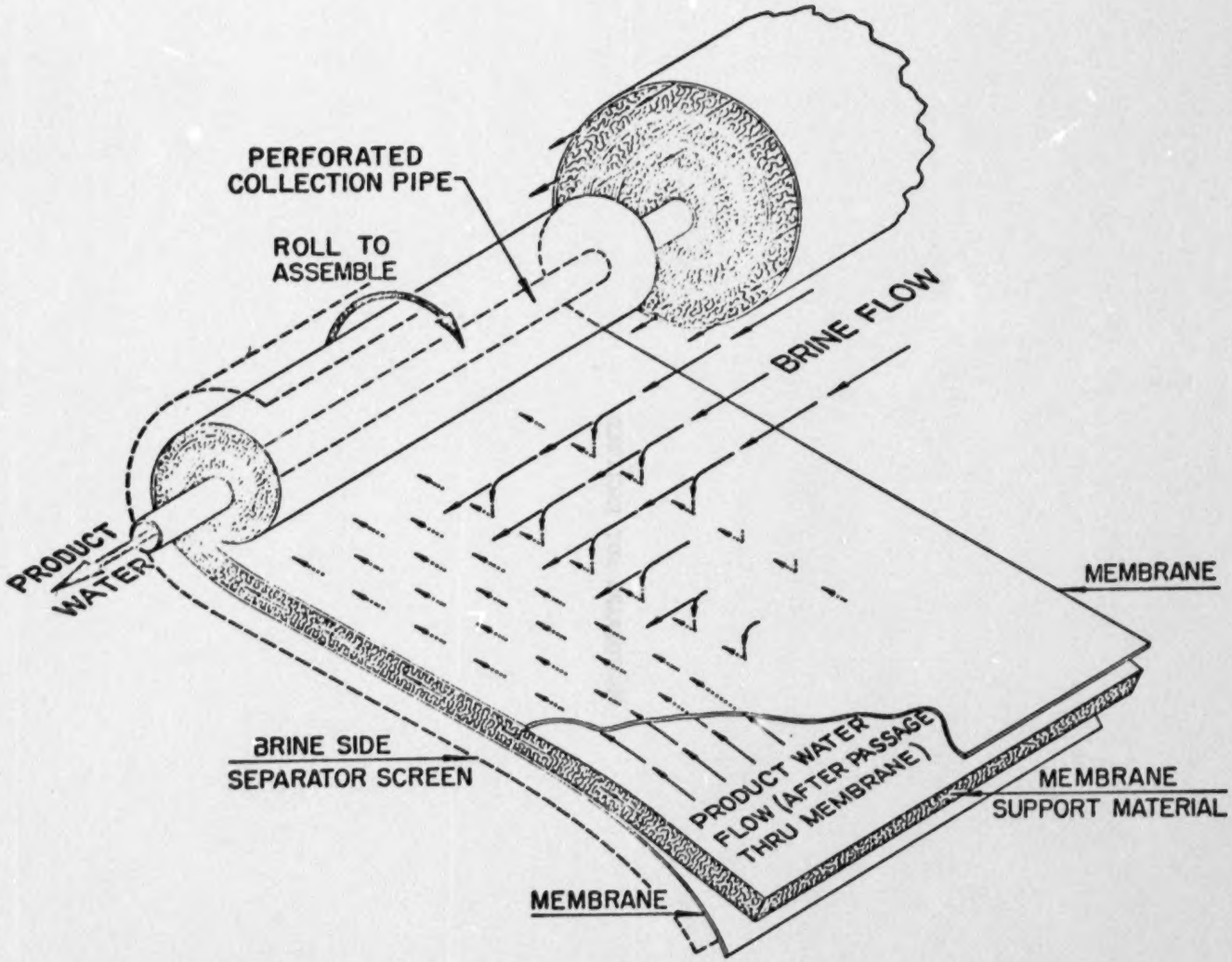

FIGURE 3: SCHEMATIC OF SPIRAL WOUND REVERSE OSMOSIS MODULE

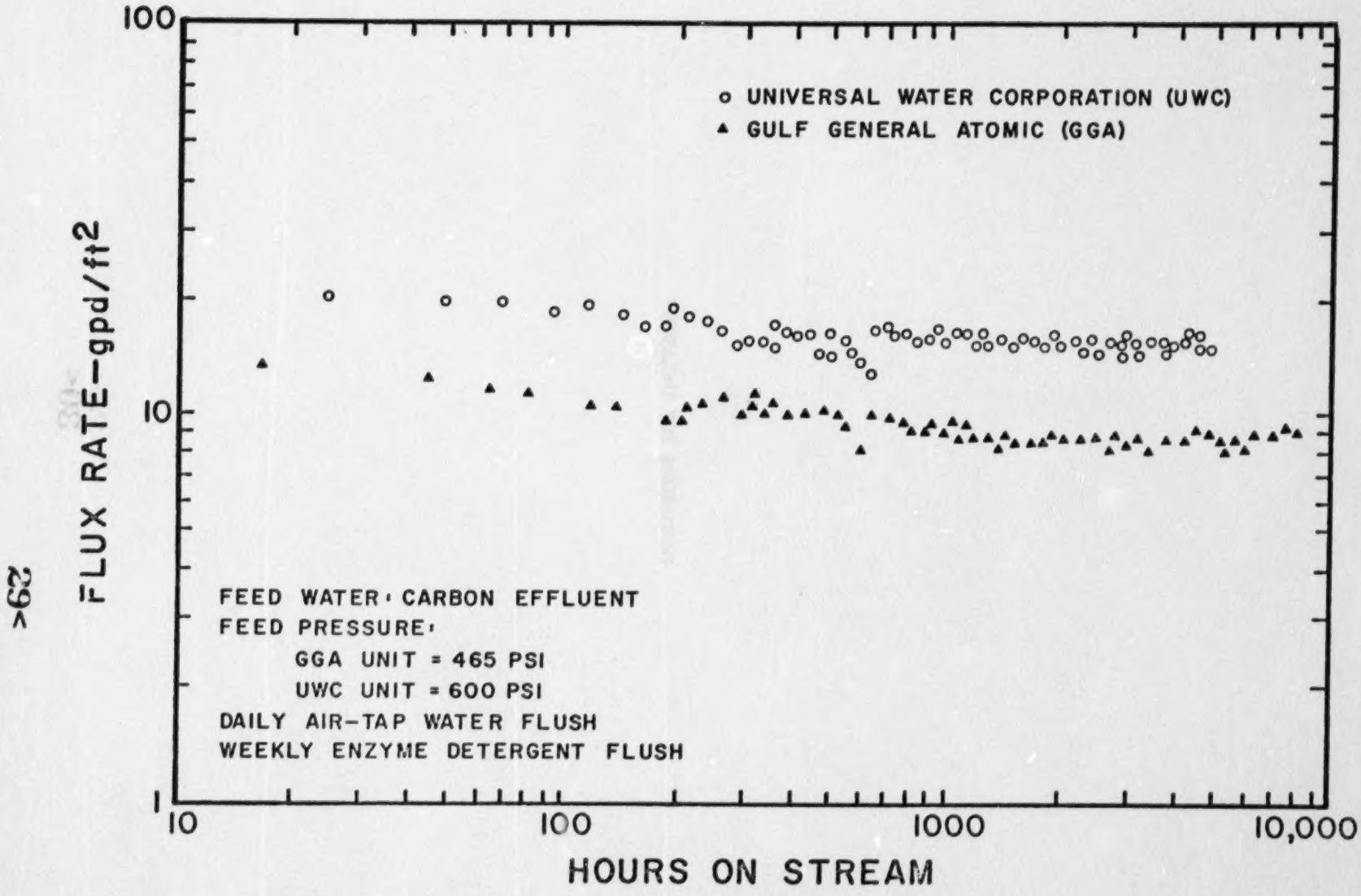

FIGURE 4: PERFORMANCE OF REVERSE OSMOSIS UNITS

PHOTOGRAPH NOT INCLUDED

FIG. 5: ELECTRODIALYSIS PILOT PLANT AT POMONA

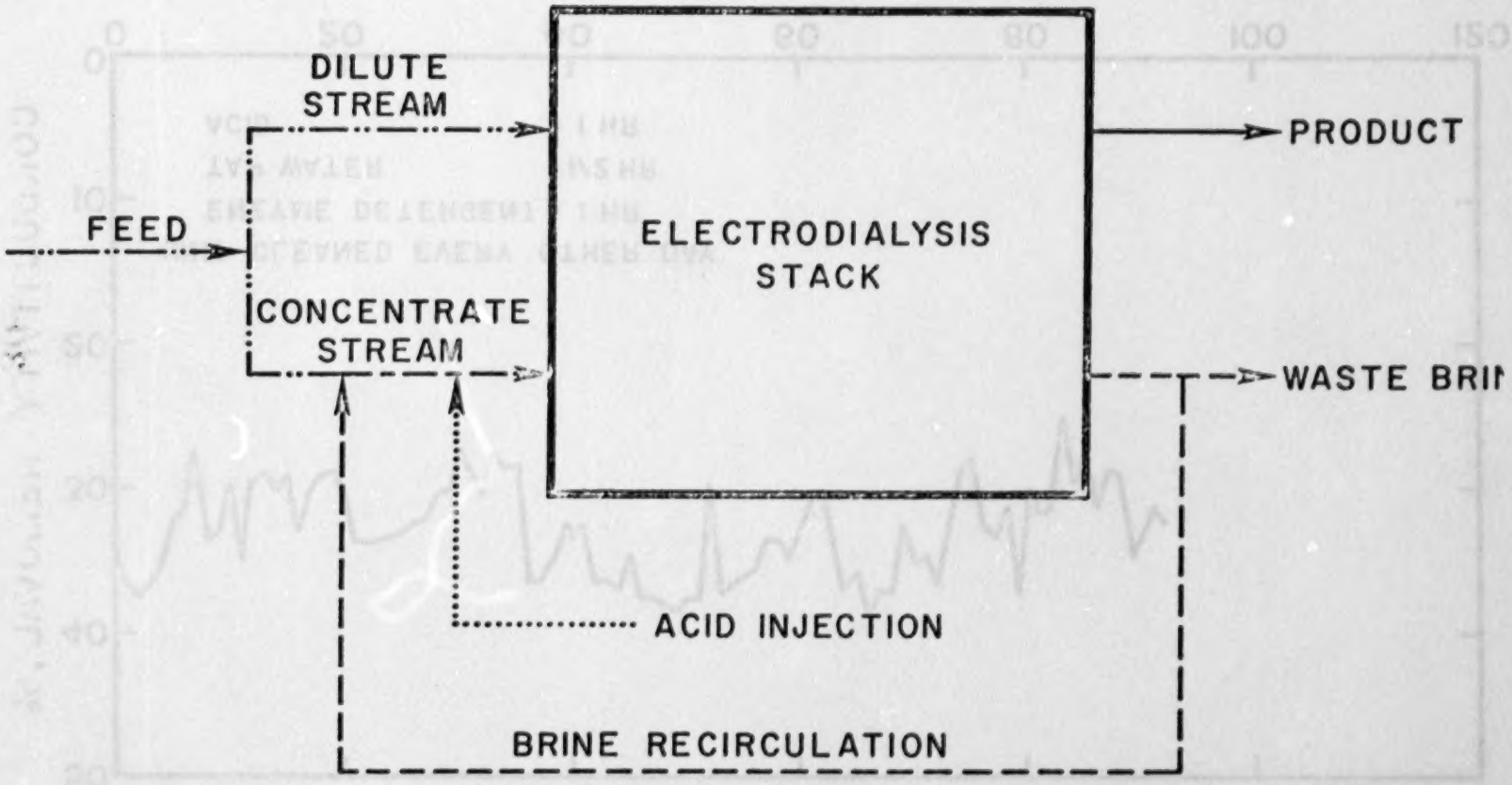

FIGURE 6: SCHEMATIC FLOW DIAGRAM OF ELECTRODIALYSIS PILOT PLANT

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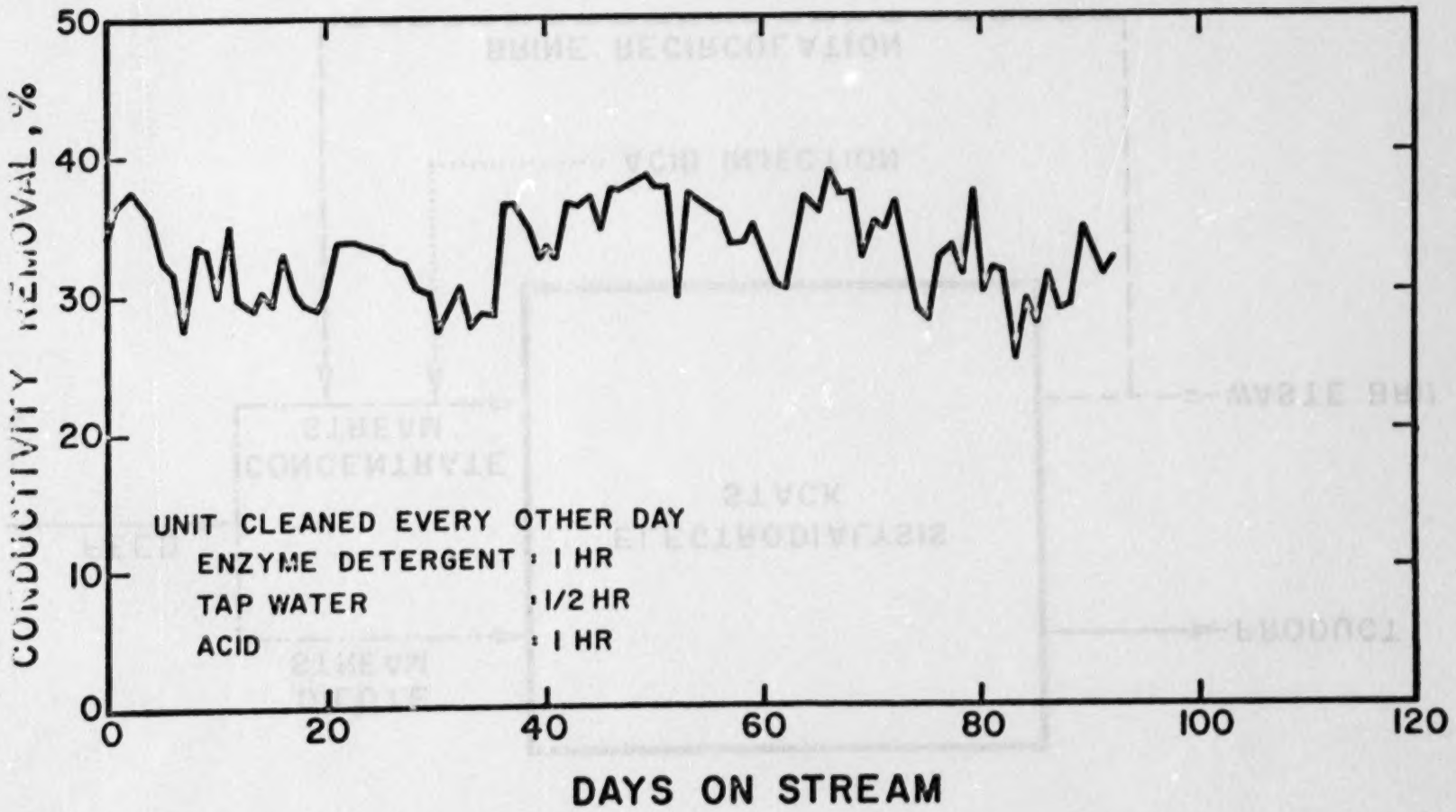

FIGURE 7: PERFORMANCE OF ELECTRODIALYSIS UNIT

PHOTOGRAPH NOT INCLUDED

FIG. 8: ION EXCHANGE PILOT PLANT AT POMONA

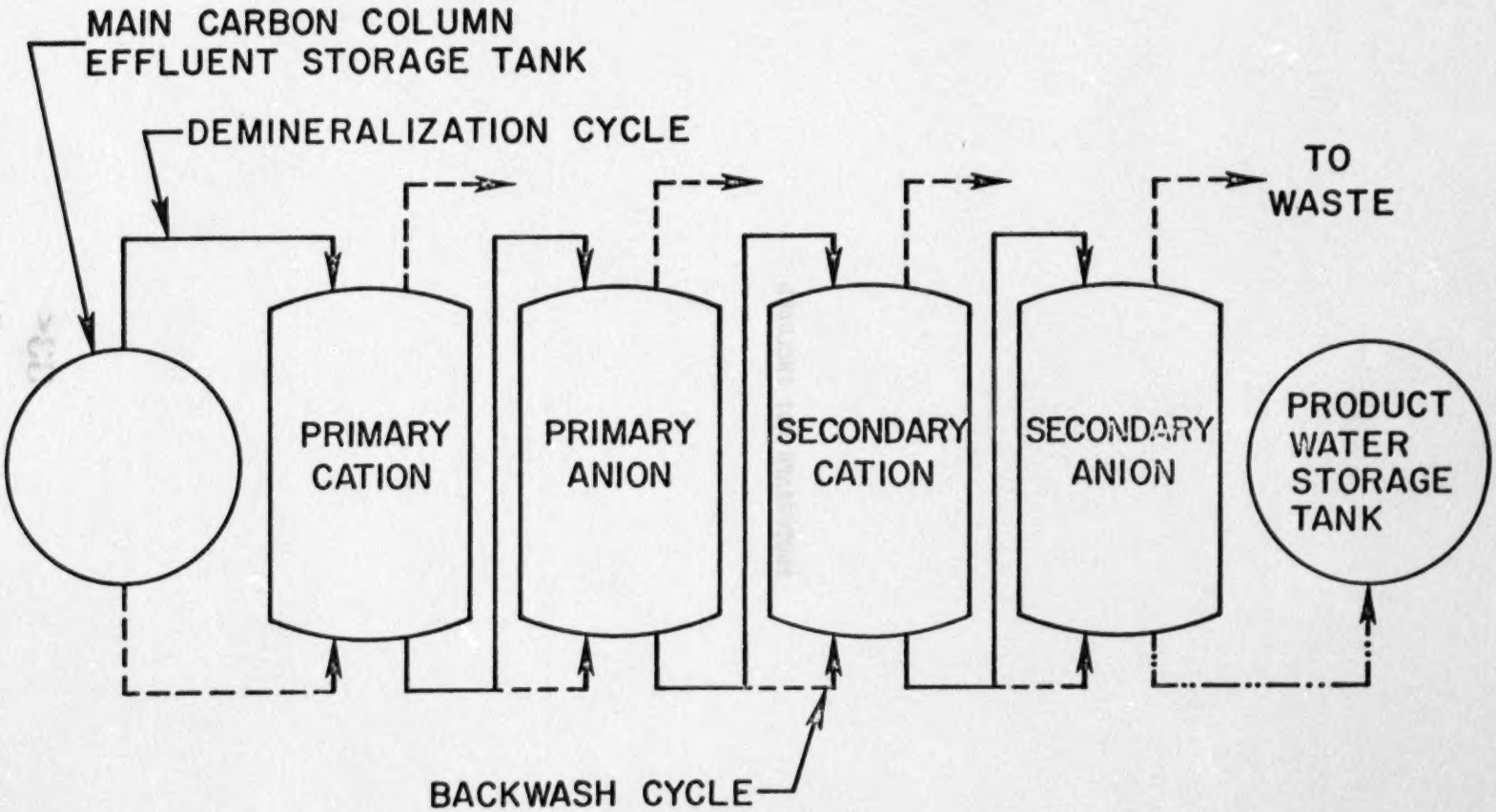

FIGURE 9: SCHEMATIC FLOW DIAGRAM OF ION EXCHANGE UNIT

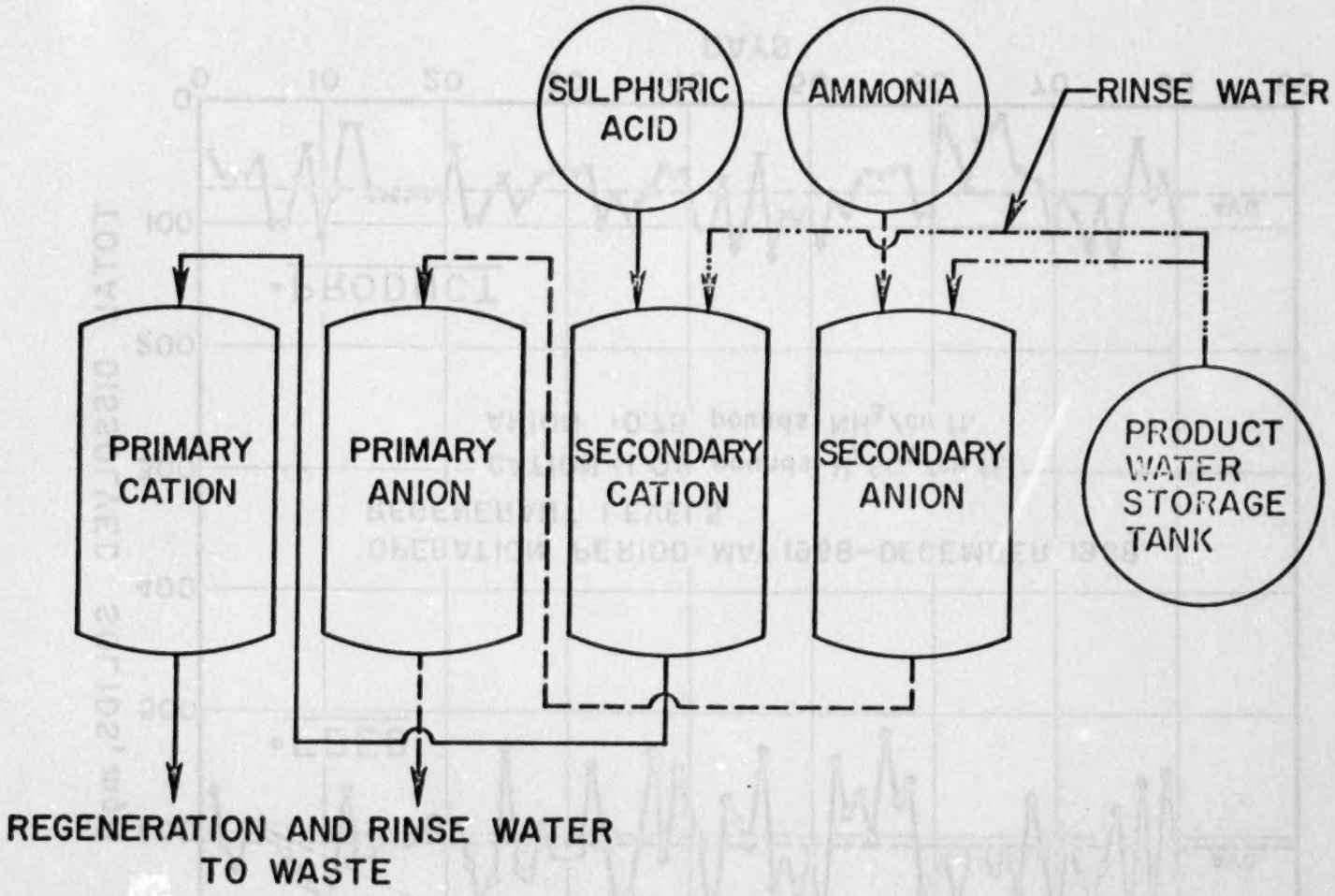

FIGURE 10: SCHEMATIC OF ION EXCHANGE REGENERATION PROCESS

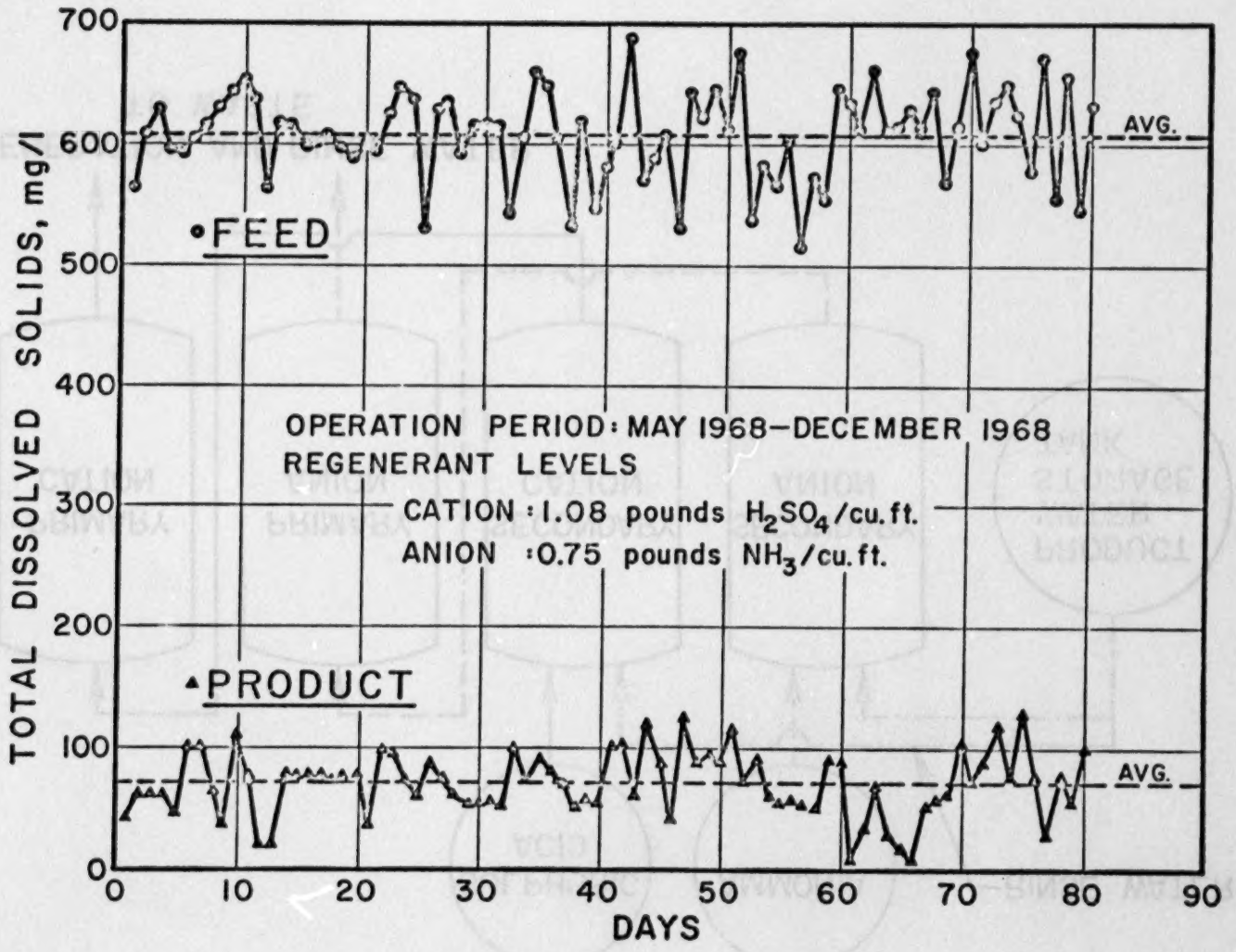

FIGURE 11: PERFORMANCE OF ION EXCHANGE UNIT

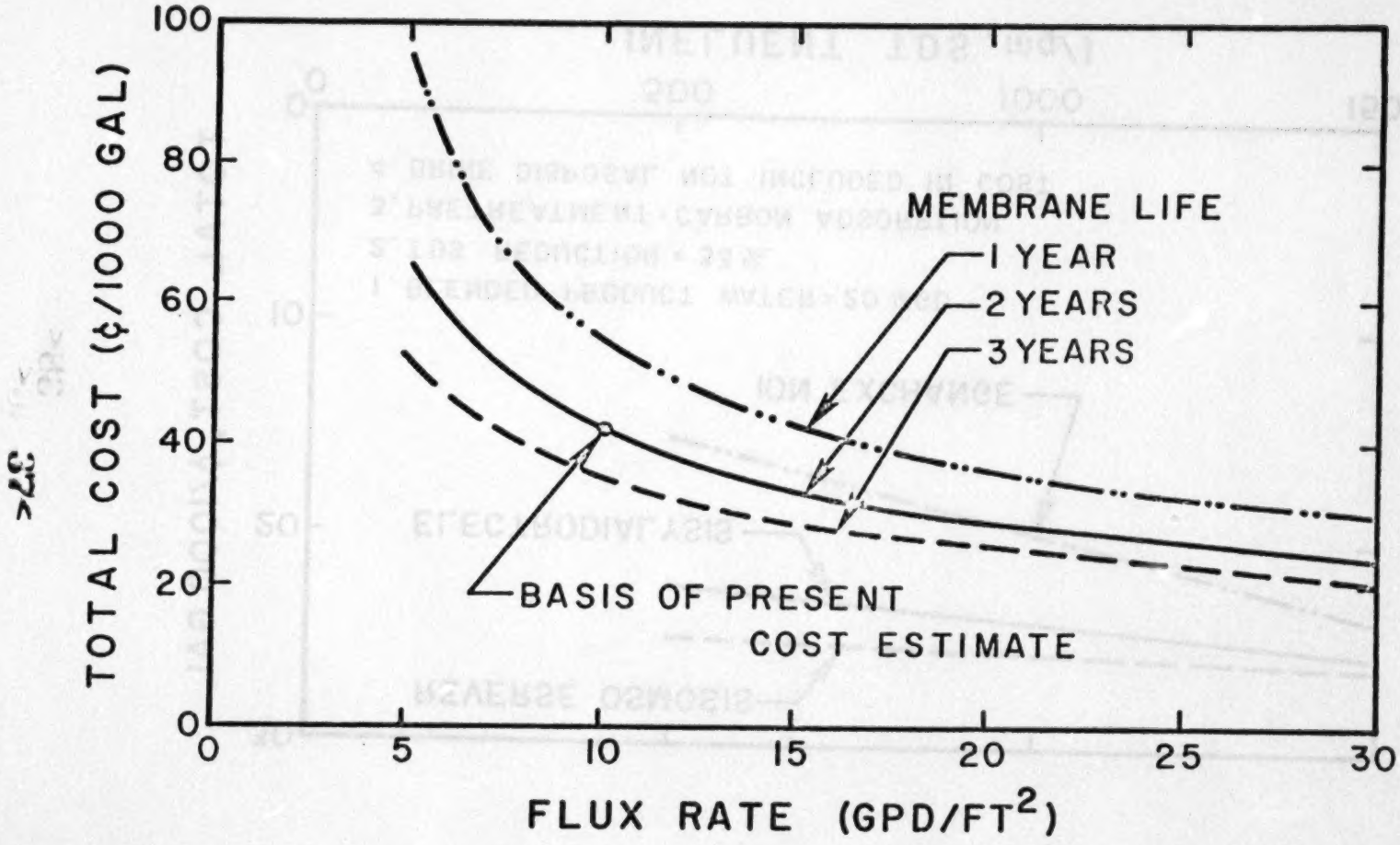

FIGURE 12: EFFECT OF FLUX RATE AND MEMBRANE LIFE ON COST OF REVERSE OSMOSIS

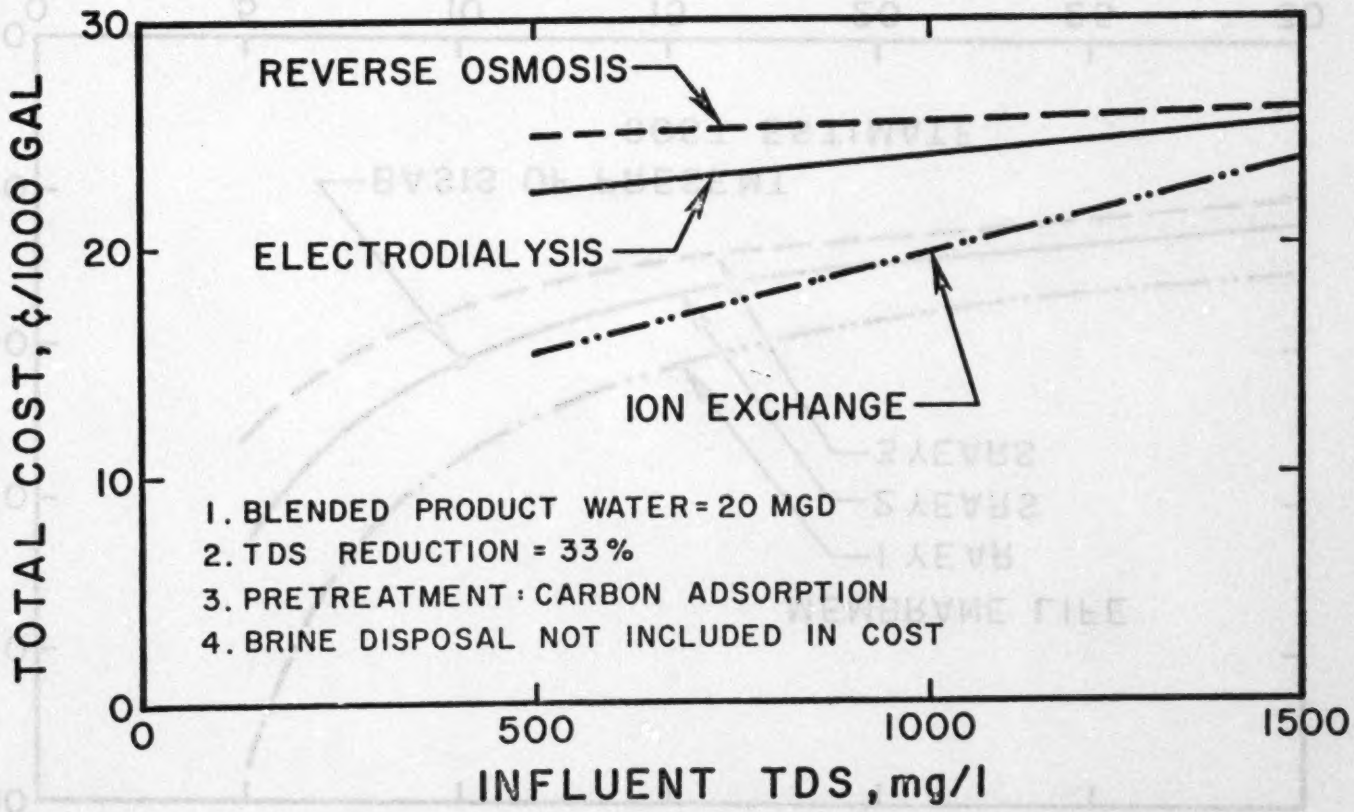

FIGURE 13: COMPARISON OF DEMINERALIZATION COSTS

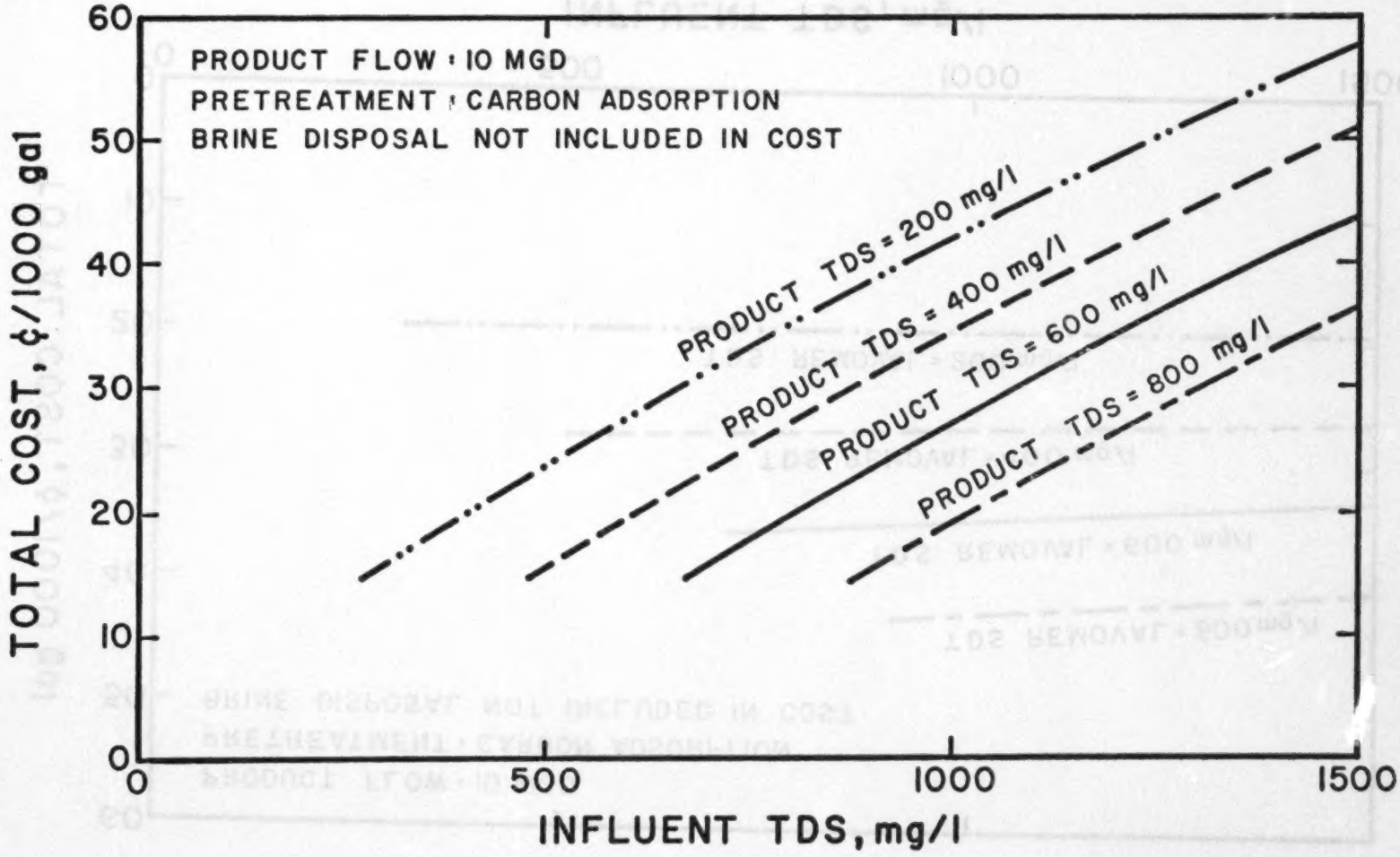

FIGURE 14: COST TO OBTAIN DESIRED PRODUCT TDS

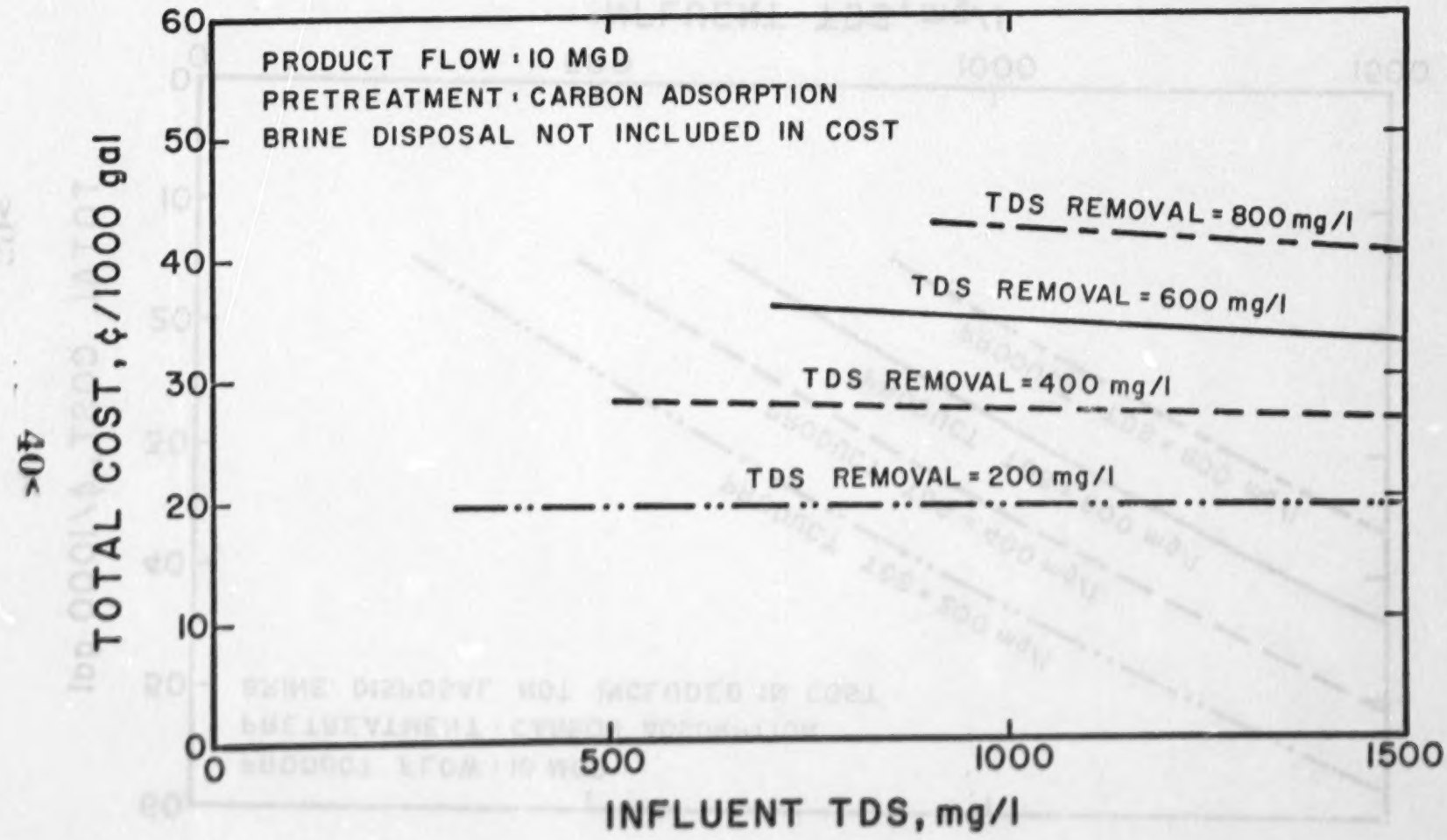

FIGURE 15: COST TO ACHIEVE DESIRED TDS REMOVAL

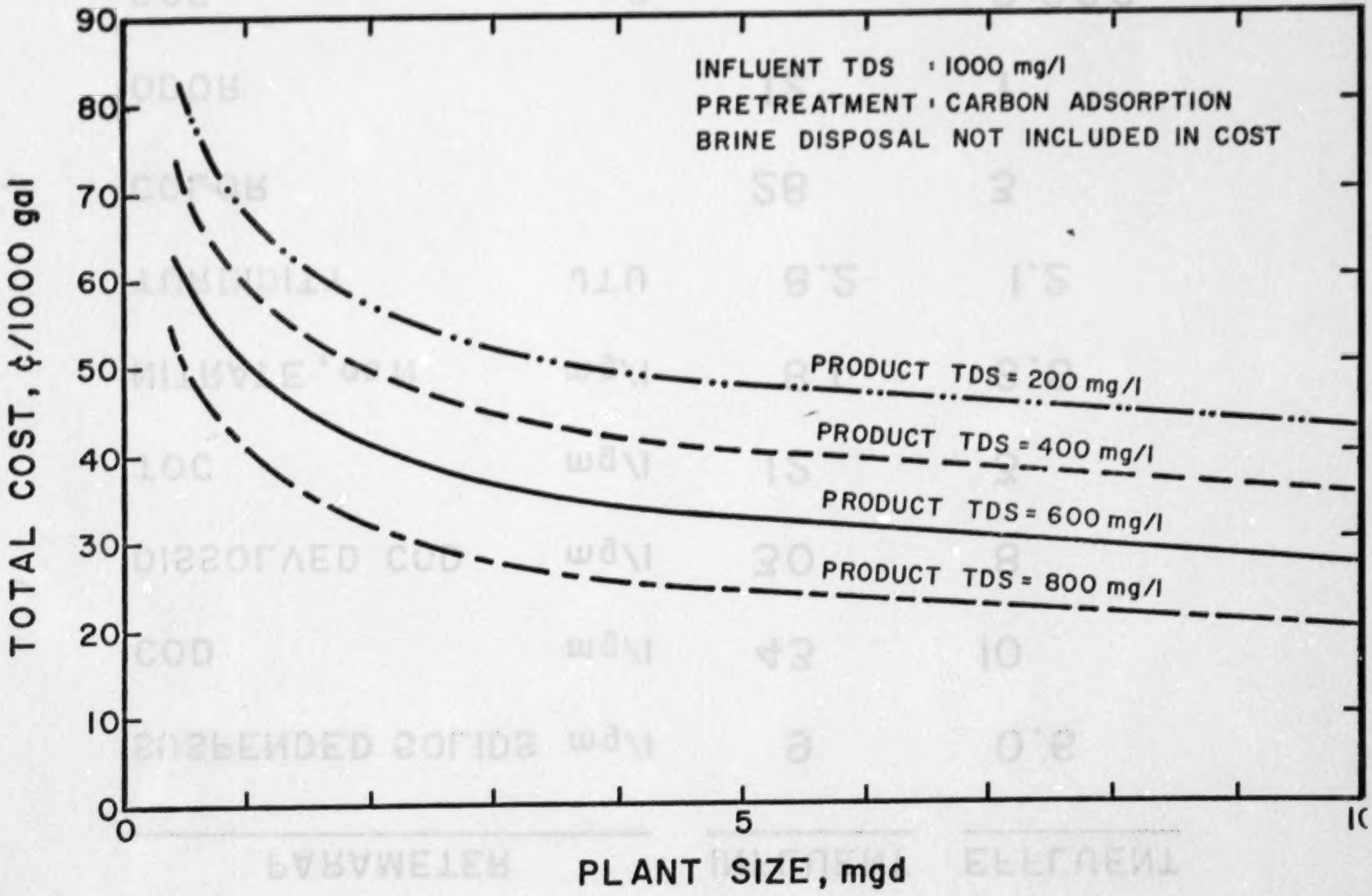

FIGURE 16: EFFECT OF PLANT SIZE UPON COST

PARAMETER		INFLUENT	EFFLUENT
SUSPENDED SOLIDS	mg/l	9	0.6
COD	mg/l	43	10
DISSOLVED COD	mg/l	30	8
TOC	mg/l	12	3
NITRATE, as N	mg/l	8.1	6.6
TURBIDITY	JTU	8.2	1.2
COLOR		28	3
ODOR		12	1
CCE	mg/l	—	0.026

TABLE 1: AVERAGE QUALITY DATA FOR CARBON ADSORPTION PILOT PLANT

TEST (mg/l)	INFLUENT	EFFLUENT	% REMOVAL
COD	8.7	1.0	88.5
NH_3-N	10.1	1.1	89.2
NO_3-N	4.9	2.4	51.0
PO_4-P	10.9	0.2	98.4
TDS	750	59	92.1

NOTES

1. 15,000 GPD PILOT PLANT
2. INFLUENT IS CARBON EFFLUENT
3. AVERAGES BASED ON 40 SAMPLES (JUNE-SEPT. 1969)
4. ANALYSES RUN ON GRAB SAMPLES
5. AVERAGE WATER RECOVERY = 75%

TABLE 2: WATER QUALITY CHARACTERISTICS OF REVERSE OSMOSIS PROCESS

TEST (mg/l)	INFLUENT	EFFLUENT	% REMOVAL
COD	9.4	8.0	14.9
NH_3-N	9.0	5.1	43.4
NO_3-N	6.2	3.1	50.0
PO_4-P	10.1	7.8	22.8
TDS	705	465	34.0

NOTES

1. 15,000 GPD PILOT PLANT
2. INFLUENT IS CARBON EFFLUENT
3. AVERAGES BASED ON 10 SAMPLES (JUNE-AUG 1969)
4. ANALYSES RUN ON 24-HOUR COMPOSITE SAMPLES
5. AVERAGE WATER RECOVERY = 83%

TABLE 3: WATER QUALITY CHARACTERISTICS OF ELECTRODIALYSIS PROCESS

TEST (mg/l)	INFLUENT	EFFLUENT	% REMOVAL
COD	10.0	3.7	63.0
NH_3-N	15.6	3.8	75.6
NO_3-N	2.9	0.4	86.2
PO_4-P	8.8	0.1	98.8
TDS	611	81	86.7

NOTES

1. 5000 GPD PILOT PLANT
2. INFLUENT IS CARBON EFFLUENT
3. AVERAGES BASED ON 20 SAMPLES (MAY-DEC 1968)
4. ANALYSES RUN ON 16-HOUR COMPOSITE SAMPLES
5. AVERAGE WATER RECOVERY = 87%

TABLE 4: WATER QUALITY CHARACTERISTICS OF ION EXCHANGE PROCESS

AMORTIZATION OF CAPITAL		¢/1000 GALLONS
$4,020,000; 20 YEARS @ 5%		8.8
OPERATION AND MAINTENANCE		
CHEMICALS	7.3	
MEMBRANE REPLACEMENT	14.4	
MAINTENANCE MATERIALS	2.6	
POWER	7.0	
LABOR	1.5	
		32.8
TOTAL		41.6

ASSUMPTIONS

1. INFLUENT TDS = 700 mg/l; EFFLUENT TDS = 100 mg/l
2. MEMBRANES: FLUX RATE = 10 GPD/FT^2; LIFE = 2 YEARS
3. WATER RECOVERY = 85%

TABLE 5: COST ESTIMATE FOR 10 MGD REVERSE OSMOSIS PLANT

AMORTIZATION OF CAPITAL		¢/1000 GALLONS
$1,830,000 ; 20 YEARS @ 5%		4.0
OPERATION AND MAINTENANCE		
CHEMICALS	4.4	
MEMBRANE REPLACEMENT	3.3	
MAINTENANCE MATERIALS	0.9	
POWER	1.9	
LABOR	2.5	
		13.0
TOTAL		17.0

ASSUMPTIONS

1. INFLUENT TDS = 700 mg/l ; EFFLUENT TDS = 450 mg/l
2. MEMBRANE LIFE = 5 YEARS
3. WATER RECOVERY = 90%

TABLE 6: COST ESTIMATE FOR 10 MGD ELECTRODIALYSIS PLANT

	¢/1000 GALLONS	
AMORTIZATION OF CAPITAL		
$1,370,000 ; 20 YEARS @ 5%		3.0
OPERATION AND MAINTENANCE		
REGENERATION		
CATION (SULFURIC ACID)	10.0	
ANION (AMMONIA)	4.2	
RESIN REPLACEMENT	2.0	
MAINTENANCE MATERIALS	0.6	
POWER	0.8	
LABOR	1.4	
		19.0
TOTAL		22.0

ASSUMPTIONS

1. INFLUENT TDS = 700 mg/l ; EFFLUENT TDS = 75 mg/l
2. REGENERATION EFFICIENCY : CATION = 85% ; ANION = 90%
3. RESIN REPLACEMENT : CATION = 10% AND ANION = 20% PER YEAR
4. WATER RECOVERY = 87%

TABLE 7: COST ESTIMATE FOR 10 MGD ION EXCHANGE PLANT

Franklin D, Dryden
and Gerald Stern

RENOVATED WASTE WATER CREATES RECREATIONAL LAKE

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Renovated Waste Water Creates Recreational Lake

In pilot studies aimed at converting a borrow pit to an aquatic park, the major hurdle proved to be the reduction of phosphorus to concentrations that limit algal growth

Lancaster, Calif., is a rural community of about 35,000 on the southern edge of the Mojave Desert about 80 miles northeast of Los Angeles. For more than 20 years the waste water of the area has been given primary treatment followed by biological stabilization in oxidation ponds. Presently, 3 million gallons per day are treated and then lost to the atmosphere by evaporation. With annual rainfall of only 2 to 3 inches, the area depends on underground sources for both irrigation and domestic water supplies. Supplemental water will eventually be imported from Northern California. In the interim, ground water must be conserved for domestic, industrial, and irrigational purposes. In recognizing the community's need for water-based recreational facilities, the Los Angeles County Engineer proposed converting an existing borrow pit to an aquatic park featuring three lakes with a combined surface area of 19 acres.

The Sanitation Districts of Los Angeles County joined with the Advanced Waste Treatment Branch of the Federal Water Pollution Control Administration, Department of the Interior (formerly the U.S. Public Health Service), in a research effort to investigate the best possible methods of renovating the oxidation pond water to a point where it would be suitable for use in the lakes. Since oxidation ponds are used in many arid areas, research groups hoped that techniques developed in Lancaster would be applicable to other localities.

The water in the oxidation ponds is unsuitable for use in the lakes without further treatment. The green algae which abound in the oxidation ponds supply oxygen to the bacteria which decompose the organic matter in the waste water. However, since algae receive their energy from light they photosynthesize and produce oxygen only during daylight hours. The water becomes supersaturated with dissolved oxygen with maximum concentrations as high as 40 milligrams per liter in Lancaster. The bacteria, however, utilize oxygen continuously and can reduce the dissolved oxygen of the water to as low as 1 mg./l. or less at night. Fish cannot survive in such an extreme environment, a fact confirmed by previous attempts to raise carp in the oxidation ponds.

In addition to sunlight, algae require carbon, nitrogen, phosphorus, and certain trace elements to live. The carbon is obtained from carbon dioxide and bicarbonate in the water, raising the pH to between 8.5 and 9.5, which is a difficult range for fish. Therefore, both the bacterial and algal populations in the oxidation pond water would have to be drastically reduced for the water to be suitable for use in recreational lakes. The bacterial population could be reduced by reducing its food supply—the organic matter and algae in the water. However, a new cycle of algae growth, organic matter production, and bacterial decomposition is sure to start unless one of the essential algal nutrients is also removed. The only essential nutrient that could readily be reduced to growth-limiting concentrations is phosphorus, and its removal has become a major objective of the study.

Research objectives

The immediate study objective was to determine and pilot the most economical method of renovating the waste water for use in the recreational lakes. However, the lack of recognized limiting quality criteria for recreational lake water required that arbitrary criteria be established as contingent objectives in evaluating processes. But these criteria were flexible and could be revised as the study revealed cost data, process capabilities, and what may be the special behavior of renovated water.

Reviews of studies by Sawyer (1947) and Malhatra (1964), consultation with algologists at the Robert A. Taft Sanitary Engineering Center, and knowledge of the recent experience of the Santee County Water District with recreational lakes supplied by soil-filtered waste water near San Diego (1966) provided the basis for the following initial quality objectives:

- Turbidity of less than 10 Jackson turbidity units (JTU).
- Phosphate concentration of less than 2 mg./l. as PO_4.
- pH of less than 8.0.
- Low concentration of chemical oxygen demand (COD) and biological oxygen demand (BOD).
- Algae counts less than 10,000 per milliliter.
- Coliform and virus determinations to meet requirements of the County Health Officer.

Subsequent experience has resulted in the revision of the phosphate objective from 2 mg./l. to 0.5 mg./l. or less. The other criteria are still considered adequate. Product water, or water produced by the selected process, is generally of better quality than would be indicated by these objectives. The turbidity objective of 10 JTU, for example, is double the average turbidity of the product water. The final turbidity is a consequence of the chemical dosage required for phosphate removal. The low turbidity makes the water clear and sparkling, which will increase its public acceptance as it enters the lake.

Oxidation pond facilities

The District 14 Water Renovation Plant features primary sedimentation followed by 240 acres of oxidation ponds. (Figure 1 shows the project site, facilities, and oxidation pond flow pattern.) Each of the eight ponds has a surface area of about 30 acres and 5- to 7-

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Franklin D. Dryden, Los Angeles County Sanitation Districts, Los Angeles, Calif. 90057
Gerald Stern, Southern California Field Station, FWPCA, Garden Grove, Calif. 92640

foot water depth. Only the first four ponds are in the treatment series; the last four are used for winter storage when evaporation rates are low and are dried out in the summer to inhibit midge propagation.

Primary effluent is divided equally between Ponds 1 and 2 and dispersed through 400-foot diffusers to avoid overloading a portion of the pond. Pond 1 discharges into Pond 2; the combined flow then passes sequentially through Ponds 4, 3, and 5 as shown. The flow pattern can be varied as desired. The average residence time to the discharge of Pond 3 is between 45 and 60 days. Pond 3 is the designated source for water to be used in the recreational lakes and was the source for all water treatment studies conducted in this project.

The project was conducted in two phases:

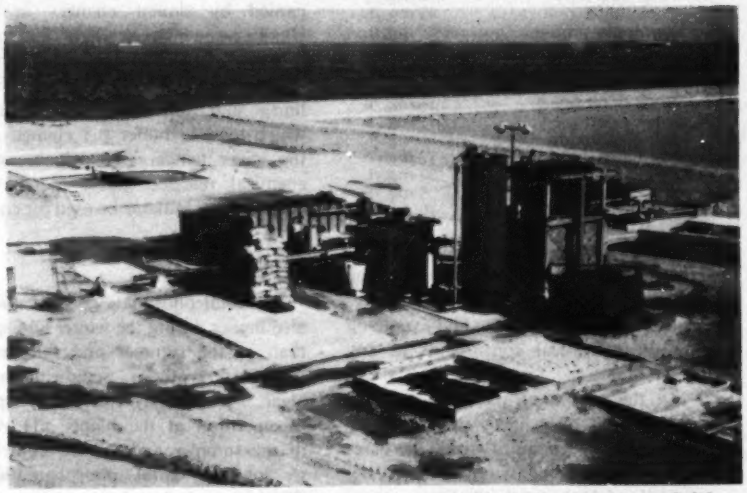
- Determining the most effective and economical process for renovation of the waste water (Phase I).
- Operating the chosen process and evaluating the product water in simulated recreational lakes (Phase II).

Phase I studies

To accomplish the desired objectives in minimum time, three research steps that would normally be conducted successively were performed concurrently. They are:

- Collection of basic data on the character of the water to be treated.
- Laboratory jar test evaluations of various coagulants to determine the most feasible chemical treatment and the optimum conditions for removing algae, other suspended material, and nutrients.
- Pilot-plant process evaluation of promising processes to develop cost and performance data in order to select preferred processes for renovating the waste water.

Analyses of the plant primary effluent



Pilot plant. *Six processes for water reuse were evaluated at Lancaster, Calif.*

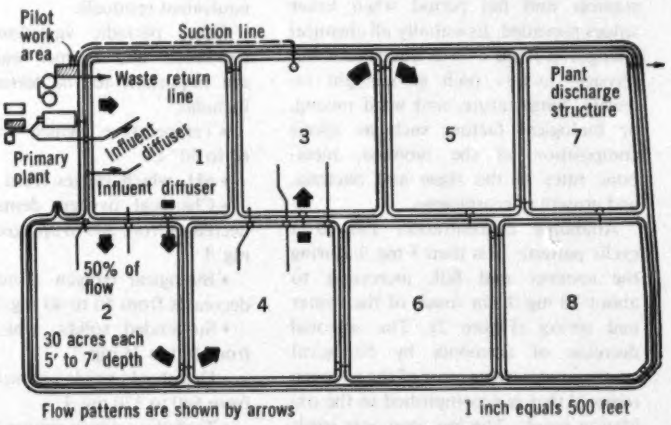


Figure 1
Oxidation ponds and study area

and of the oxidation pond water began in October 1963. Grab samples were collected from the pond and analyzed for selected chemicals and algae genera and numbers. An automatic sampler was installed on the primary effluent in July 1964, to obtain more representative data. The average characteristics of the primary effluent are:

pH	7.2
Total alkalinity	258 mg./l.
Phosphate	45 mg./l.
Ammonia-nitrogen	27 mg./l.
COD	392 mg./l.
Suspended solids	90 mg./l.
Dissolved solids	553 mg./l.
Organic nitrogen	11 mg./l.
Nitrate-nitrogen	0.1 mg./l.
Nitrite-nitrogen	<0.01 mg./l.
Hardness	77 mg./l.
Calcium	32 mg./l.
Magnesium	3 mg./l.
Sulfate	70 mg./l.

Pondwide sampling established that the long detention times within the ponds and frequent strong winds resulted in excellent mixing and averaging of most chemical constituents at any given time.

In the course of the study we observed that, to achieve equivalent results, greater chemical doses were required during the winter and spring period of high total alkalinity, phosphate, and ammonia than during the summer and fall period when lower values prevailed. Essentially all chemical changes in Pond 3 were traced to either physical factors such as sunlight intensity, temperature, and wind mixing, or biological factors such as specie composition of the biomass, metabolic rates of the algae and bacteria, and growth of crustaceans.

Ammonia concentration showed a cyclic pattern—less than 3 mg./l. during the summer and fall, increasing to about 20 mg./l. for much of the winter and spring (Figure 2). The seasonal decrease of ammonia by biological synthesis represents most of the nitrogen removal that is accomplished in the oxidation ponds. The low ammonia levels in the summer correlate with the period of rapid metabolism. The high levels in the winter correspond to the period when low sunlight intensity and low temperatures reduce the rate of photosynthesis. Nitrate and nitrite concentrations are generally low throughout the year. However, in the spring of 1966 as temperatures were rising, nitrite values reached 10 mg./l. for about a week before the development of nitrate-producing bacteria, which converted some of the nitrite to nitrate. Denitrification may also have occurred; nitrate values never exceeded 2 mg./l., while the nitrite dropped almost to zero. Organic nitrogen has been observed as high as 20 mg./l., coinciding with high algal counts.

Ammonia variations are also accompanied by similar changes in total alkalinity, which averages 260 mg./l. in the winter and spring and 220 mg./l. in the summer and fall. The higher alkalinity and ammonia concentrations, which tend to buffer pH changes, and the lower temperature, which reduces chemical reaction rates, require that additional coagulants be used for equivalent treatment.

Total phosphates

The total phosphate concentration is also higher during the winter and spring than in the summer and fall period. Biological synthesis, sedimentation of algae, and possibly calcium phosphate precipitation at the higher pH values of the summer and fall all contribute to lowering total phosphate levels. The low total phosphate concentrations permit low coagulant dosages for equivalent residuals.

Other periodic variations between the colder and warmer seasons which are important to the tertiary process include:

- Temperature, which varies from 6° to 30° C.
- pH, which ranges from 7.5 to 9.6.
- Chemical oxygen demand, which decreases from 300 to approximately 200 mg./l.
- Biological oxygen demand, which decreases from 50 to 40 mg./l.
- Suspended solids, which decrease from 100 to 75 mg./l.
- Dissolved solids, which decrease from 640 to 570 mg./l.
- Turbidity, which ranges from 90 to 170 JTU in the cold season and from 40 to 150 JTU in the warm season.

Algae genera and predators

The oxidation ponds contain about 66 algae genera in varying concentrations (50,000 to 700,000 counts per ml.) throughout the year. *Scenedesmus* is the most common, although *Euglena*, *Ankistrodesmus*, *Phacus*, *Oöcystis*, *Chlorella*, and *Nitzschia* have also been dominant.

The most common crustaceans found at random in the oxidation ponds at different times are *Daphnia* and *Cyclops*. These algae predators contribute to the variation in algae counts and algae genera.

The oxidation ponds are very effective in reducing both bacteria and virus levels. The bacteria reductions, after 45 to 60 days' detention, were more than 99.7% (Figure 3). Viruses were detected in 96% of primary effluent samples, and in only 8% of the Pond 3 samples. Polioviruses I, II, and III, the adeno group, coxsackievirus B-3, echovirus 7, and reovirus have been identified in the primary effluents. In oxidation Pond 3 waste water, one sample contained polio II and three samples contained an unidentified virus.

Laboratory studies

Laboratory studies included jar test evaluation of coagulants. The object was to determine the most effective coagulants and coagulant aids, their required dosages, the best flocculating conditions, and relative costs.

The jar test apparatus consisted of a 10-place stirrer equipped with a variable speed paddle drive. All tests were performed on water from oxidation Pond 3 following the procedures suggested by Cohen (1957).

To facilitate screening a maximum number of samples, the effectiveness was rapidly estimated by a turbidity measurement. Additional chemical analyses were performed on particularly promising samples.

The coagulant combinations tested are too numerous to report. The major coagulants were:

- Aluminum sulfate [$Al_2(SO_4)\cdot 14H_2O$] as a commercial grade alum, with and without pH adjustments and other coagulant aids.
- Calcium hydroxide [$Ca(OH)_2$] as lime, both high-calcium [90% $Ca(OH)_2$] and the less expensive dolomite [58% $Ca(OH)_2$ and 41% $Mg(OH)_2$].
- Ferric sulfate [$Fe_2(SO_4)_3$], 70% pure, 30% inert.
- Dow C-31 cationic polyelectrolyte. (Dow NCl118, UCAR-149, and Nalco 600 cationic polyelectrolytes were also tested. Dow C-31 test results were very

similar to the other three cationic polyelectrolytes.)

• Sulfuric acid (H_2SO_4) at 66° Baumé.

Jar test studies were run to determine costs for the primary coagulants (Figure 4). Dolomitic lime was used in the cost analyses even though high-calcium lime was actually used in pilot studies because it was easier to handle. The jar test showed the two products to be equally effective at equivalent dosages. Ferric sulfate was omitted from further primary coagulant studies due to its higher cost.

The majority of the jar tests were conducted with alum, lime, and various cationic polyelectrolytes as coagulants. In addition, sulfuric acid and carbon dioxide were used for pH adjustment in conjunction with alum coagulation.

Figure 2

Phosphate and ammonia concentrations in Pond 3

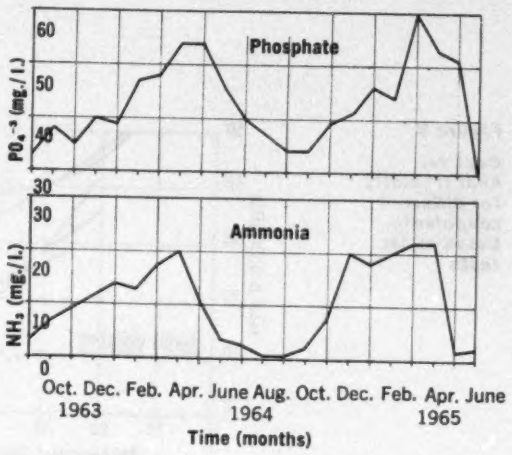


Figure 3

Median bacteria counts through oxidation ponds

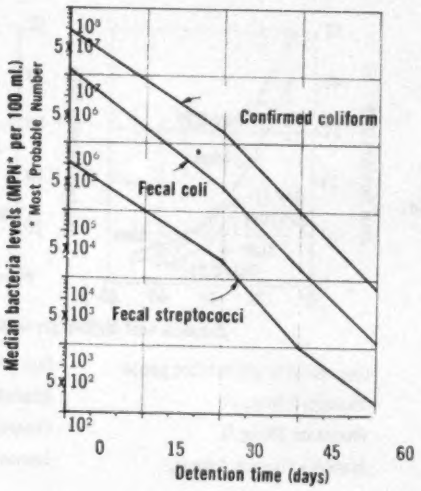
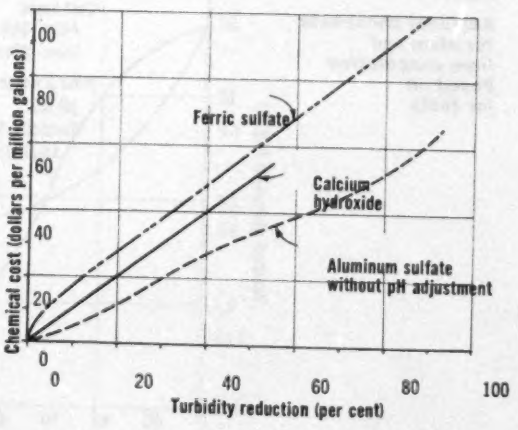


Figure 4

Cost vs. removal efficiency for primary coagulants based on jar tests



Coagulant studies

Tests were also run for primary coagulants and coagulant combinations (Figure 5), including the overall effect of levels of chemical constituents in Pond 3, to determine their cost.

Figure 6 shows the effectiveness and costs of coagulant combinations during periods when the difference in chemical requirements is related to changes in the characteristics of Pond 3 water. Lime was less effective than alum in the spring period, although it was competitive with alum in the fall. As for total phosphate removal, alum coagulation was much more successful than lime, in the colder season, for reducing phosphate concentrations (Figure 7). With lime coagulation, a substantial colloidal precipitate remained, which could account for the higher phosphate residual.

The use of cationic polyelectrolytes or acid for pH adjustments materially reduced the quantities of alum required to accomplish turbidity objectives in each seasonal period, although the coagulant cost in the spring was much higher than in the fall. However, cationic polyelectrolytes and sulfuric acid do not remove soluble phosphate. Consequently, alum in combination with acid or polyelectrolytes is not as effective in removing phosphate so the larger dosage of alum alone. Since alum was the most effective coagulant, it received the most attention in pilot work.

Jar test studies were also used to determine optimum conditions for successful alum coagulation of Pond 3

Figure 5

Cost vs. final turbidity for different coagulants based on jar tests

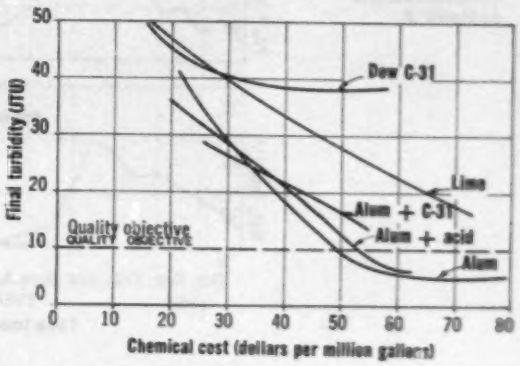
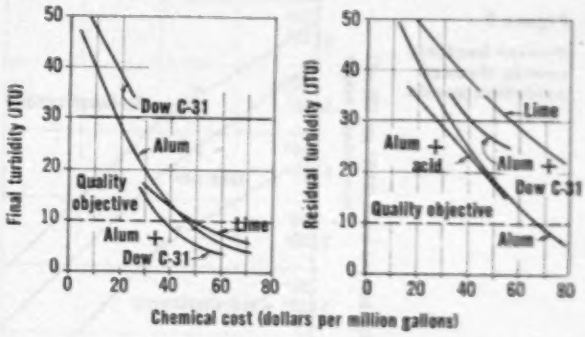


Figure 6

Cost vs. final turbidity for different coagulants during high and low alkalinity and nutrient period, based on jar tests

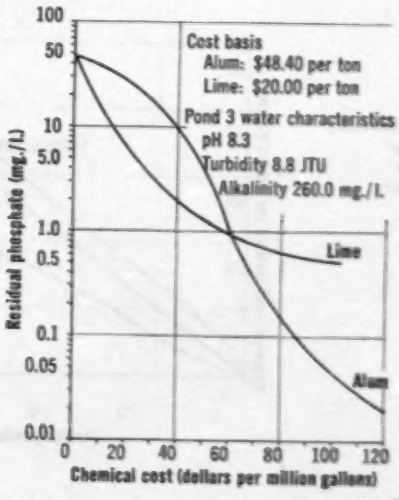


Low alkalinity and nutrient period
Alkalinity 220 mg./l.
Phosphate 35 mg./l.
Ammonia nitrogen 2 mg./l.

High alkalinity and nutrient period
Alkalinity 260 mg./l.
Phosphate 55 mg./l.
Ammonia nitrogen 20 mg./l.

Figure 7

Residual phosphate for alum and lime coagulation based on jar tests



water for phosphate removal. These studies showed that with or without the addition of acid and base to change the initial pH and alkalinity, phosphate residuals were minimum when the final pH was approximately 6.0 (Figure 8). Increasing the alum dosage from 150 to 300 mg./l. also decreased the minimum phosphate residual. Others have found that the equilibrium constant for alum indicated phosphate can be removed to 0.04 mg./l. and that the pH for optimum removal is close to 6.0.

Pilot plant studies

The pilot plant studies were designed to evaluate and compare various treatment processes and to obtain reasonable cost estimates. The pilot area was arranged around a central run of influent and effluent piping with connections for six concurrent processes. Oxidation pond water was delivered to the pilot area from mid-depth on the north side of Pond 3 through a 1600-foot, 6-inch-diameter pipeline, and waste and product water were pumped back into Pond 1. Pilot units ranged in capacity from 1 to 50 gallons per minute (g.p.m.).

Initially, experiments were conducted to remove algae separately from the dissolved nutrients in the hope of producing a marketable algae for use as a poultry feed. A small microstrainer (23-micron screen), a pressure sand filter, and three types of diatomaceous earth filters were tested. These processes failed to produce the desired results. Removals with the microstrainer were totally inadequate and blinding by the bodies of crustacea and other foreign material occurred quite rapidly. The pressure sand filter removed a good percentage of the algae but not enough to be economical. Diatomaceous earth was quite successful in removing the algae, although color and turbidity of the product water were still high. The estimated value of the recovered algae was $25 per million gallons (based on $100 per ton), but the process costs for short filter cycles, separating the algae from the cake, and drying them, far exceeded the product value. More recent evaluations by Dr. William Oswald (University of California, Berke-

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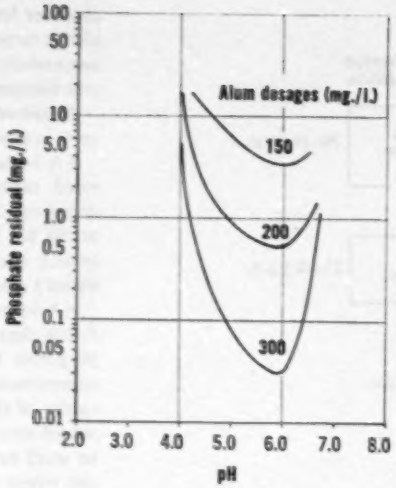
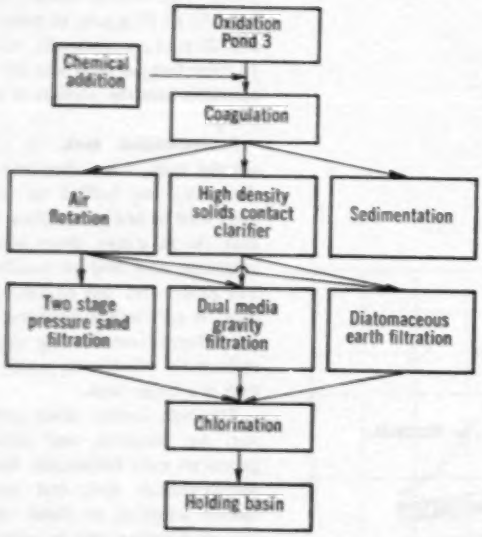
Figure 8

Phosphate residual vs. pH based on jar tests





Pilot plant flow sheet (phase I)

Figure 9

ley) have shown some algae to be a substitute for fish meal, value per ton: $200.

Thereafter, the study concentrated on the best possible processes for clarifying the water. In spite of the potential savings to be gained by completely removing turbidity and dissolved nutrients in a single process, preliminary pilot work indicated that a combination of processes would be required to achieve the desired quality objectives. The first process would materially reduce suspended matter and nutrients by chemical treatment, and the water would be polished by filtration and disinfected by chlorination (Figure 9).

Chemical processes

Initially, the quality objectives for the chemical processes were a turbidity of 20 JTU or less and total phosphate concentration of less than 2 mg./l. Subsequent algal regrowth studies emphasized the need to reduce total phosphate levels to less than 0.5 mg./l. by using larger dosages of alum, which also reduced turbidity levels to the 5- to 10-JTU range. Turbidity was used to compare the relative effectiveness of the pilot processes in screening tests because of the ease and rapidity of measurement. The following types of pilot equipment were tested:

Portable water treatment plant. A completely self-contained trailer-mounted water purification unit of 25-g.p.m. rated capacity loaned to the project by the U.S. Army. It featured an upflow clarifier with a central mixing and flocculating chamber. Results were not satisfactory because of the release of supersaturated dissolved oxygen and other gases which buoyed the floc to the surface.

High density solids contact clarifier. A complete lime-coagulation and recarbonation water treatment unit of 25-g.p.m. capacity with provision for sludge recycle and auxiliary chemical addition. The first of two 10-foot high, 4-foot diameter vertical columns contains rapid mix, coagulation, and flocculation zones near the top with upflow clarifier and sludge collection zones in the bottom. The second column or recarbonator contains inverted trays

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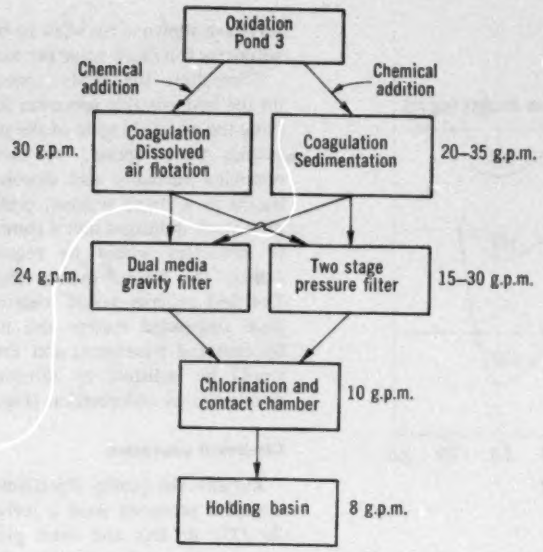


Continuous pilot plant flow sheet (phase II)

Figure 10

to adjust pH by adding CO_2 and a chamber for supplementary settling and sludge recycle. The unit did not operate successfully at its rated capacity but was adequate at 10 to 15 g.p.m.

Dissolved air flotation units. Pilot units in two sizes were used in this study:

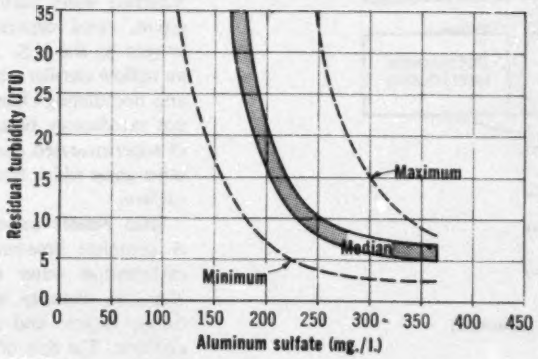
- A 1-square foot air flotation unit—rated capacity 0.3 to 3.0 g.p.m., air dissolved into auxiliary water stream at 60 to 70 pounds per square inch (p.s.i.), manually skimmed, operated at about 1 g.p.m.
- A 6-foot diameter, 27-square foot × 6-foot deep air flotation unit rated at 50 g.p.m. Coagulated water entered a supersaturated mixing chamber in the center of the 6-foot high tank. Air dissolved into the recycle water is released in small bubbles that lift the floc to the top where it is skimmed into a trough. The clarified water flows to the bottom of the tank and up to and over a circular weir around its periphery. The unit was operated at flow rates between 20 and 50 g.p.m. with most runs at 30 or 40 g.p.m. The recycle stream was varied from 10 to 25 g.p.m. at pressures of 40 and 20 p.s.i., respectively. Air at about 15 cubic feet per hour was introduced by eduction into the suction of the recycle pump.

Sedimentation tank. A 1200-gallon circular tank, 4 feet deep and 7.5 feet in diameter, was baffled to serve for a brief trial of horizontal-flow sedimentation. At 11 g.p.m. there was a 2-hour detention time and an overflow rate of 340 gallons per day (g.p.d.) per square foot. A submerged discharge protected the effluent from floating algae. It was sufficiently effective to justify construction of a larger unit.

The high density solids contact clarifier, air flotation, and sedimentation processes were technically feasible. The sedimentation tank test results were almost identical to those obtained in the air flotation unit in contrast to the very poor results obtained in the truck-mounted upflow clarifier used in the early part of the study. The pilot-plant tests substantiated the jar tests results in that alum remained the most effective chemical coagulant. Thus, both air flotation and horizontal sedimentation with alum as primary coagulant were

Figure 11

Residual turbidity vs. aluminum sulfate prior to filtration (pilot plant)



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chosen as the preferred processes to be evaluated in Phase II.

Filtration equipment. Polishing of primary process effluent by filtration provides a safety factor and produces a water of such clarity that its appearance will be pleasing to the public. Both diatomaceous earth filters and sand filters were tested. Diatomaceous earth filters were the following types:

- A low pressure reversible cake diatomaceous earth filter of 0.5 to 3 g.p.m., operated at approximately 1 g.p.m. for pilot tests.
- A truck-mounted 25-square foot pressure filter.
- A wound-wire pressure filter.
- A vertical leaf swimming pool pressure filter.
- A 1-square foot bench-scale pressure filter.
- A 50-square foot tube and shell pressure filter.

Sand filters tested were:

- A two-stage pressure sand filter of 2-foot depth and 2.2-square foot surface area per stage.
- Six 3½-inch-diameter, 0.06-square foot lucite gravity sand and dual media filter columns.
- A 12-square foot gravity sand or dual media (anthrafilt-sand) filter.

Diatomaceous earth filter effluents were consistently better than effluents from the dual media or pressure sand filters. However, diatomaceous earth filter cycles did not exceed 3 hours, resulting in excessive diatomaceous earth usage and high costs (estimated between $80 and $200 per million gallons). The short filter cycles were caused by blinding of the filter by algae and other particulate matter not removed in the previous separation process. The compressibility of the gelatinous floc contributed to the rapid blinding in spite of diatomaceous earth body feed rates of up to 90 mg./l. and influent water turbidities as low as 3 JTU.

Pressure sand and dual media filtration both reduced influent turbidities by 25 to 50% resulting in filter effluents with turbidities of 10 JTU or less when the effluent turbidity from the chemical process was between 10 and 20 JTU. Longer operating cycles and the reuse of the filter media provided a substantial cost advantage for sand and dual media filter over the diatomaceous earth units.

Preferred processes

The combined processes to accomplish the quality objectives at lowest cost were:

- Alum coagulation.
- Either dissolved air flotation or plain sedimentation.
- Either pressure sand or dual media gravity filtration.
- Chlorination.

These combined processes were arranged in combinations and automated sufficiently to permit their 24-hour per day operation while being attended only 8 hours per day (Figure 10). The processes were operated for a full year with the product water being monitored and fed to a small simulated lake to demonstrate the continuous production of high quality water, to compare the alternative chemical treatment and filtration processes for reliability at all times of the year, and to evaluate the behavior of the product water in the simulated lake.

The horizontal flow sedimentation unit was designed for 20 to 50 g.p.m. at overflow rates between 300 and 700 g.p.d. per square foot. The effluent was removed by a submerged launder to avoid floc that might float to the surface. This feature was found to be unnecessary since there was almost no floating floc in a year of operation. A mechanical scraper removed the settled sludge.

Although there was almost no difference in quality characteristics during a year of comparative operation, the sedimentation and dual media gravity filtration systems were selected over the flotation and pressure sand filter systems on the subjective basis of simplicity of operation and general reliability. Alum dosages were increased to 300 mg./l. during the evaluation study to reduce phosphate to its lowest practical minimum. As later tests established, algae growth is not noticeably inhibited at phosphate concentrations above 0.5 mg./l.

Residual turbidity as a function of aluminum sulfate dosage for pilot plant air flotation and horizontal sedimentation tests was averaged over the Phase I and Phase II study (Figure 11). Also, residual phosphate was plotted as a function of alum dosage for pilot plant tests conducted in the Phase I and Phase II study, and averaged for the high alkalinity–high phosphate and low alkalinity–low phosphate periods (Figure 12). These studies show the effectiveness of increasing the alum dosage to 300 mg./l. or more to meet both the turbidity and total phosphate quality criteria for the recreational lake water.

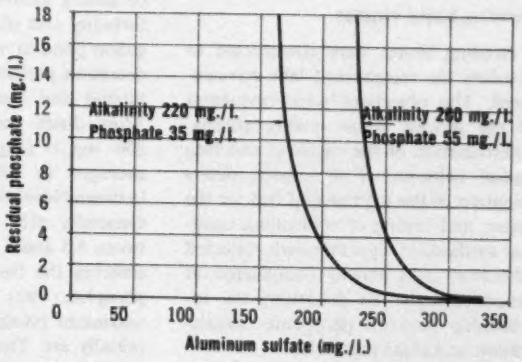
Final selection of processes

The process chosen for converting the oxidation pond water for use in recreational lakes features:

- Coagulation with approximately 300 mg./l. of commercial grade aluminum sulfate and 20 minutes of floc-

Figure 12

Residual phosphate vs. aluminum sulfate prior to filtration (pilot plant)



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culation with a typical water treatment plant paddle flocculator.

- Sedimentation with an overflow rate of about 400 g.p.d. per square foot in a horizontal flow tank equipped with sludge scrapers. The sedimentation tank will be covered to prevent wind-generated currents and turbulence.
- Filtration through a dual media gravity filter comprised of 18 inches of 0.5-mm. anthracite over 8 inches of Number 20 sand.
- Chlorination at about 6 to 15 mg./l. Chlorine may be added prior to the sedimentation tank (to reduce crustacean populations reaching the filter) or after the filtration step.
- Minimum 8-hour retention in a chlorine contact chamber.
- Skimmings and sludge from the sedimentation tank and backwash water from the filter will be returned to the inlet of the plant. Most solids will be removed with the primary sludge and digested.

The characteristics of the processed water are compared with those of Pond 3 in Table 1.

A 500,000-g.p.d. facility is being designed to supply the 19-acre recreational lakes. This added supply will prevent dissolved solids in the lake from increasing beyond 700 mg./l. due to evaporation. The water will also be used to irrigate the surrounding park. The capital cost of the plant is estimated at about $150,000. Operating costs are estimated at $184 per million gallons, chemical costs accounting for $70 per million gallons. When expanded to 3-million gallons per day (m.g.d.) capacity, the total cost of capital, operation, and maintenance is estimated at about $150 per million gallons compared to about $200 per million gallons for imported water.

Holding basin studies

Holding basins were constructed to simulate the recreational lake environment. The objectives were evaluation of the process water quality criteria, determination of the chemical and biological behavior of the water, determination of the tolerance of fish for the water, and testing of controlling auxiliary methods of algal regrowth. Selected laboratory tests were also conducted on processed water to determine the relationship between phosphate concentration and algae regrowth.

Three different basins were used: several 1200-gallon, 7.5-foot diameter, 4-foot deep rubber tanks; two 10,000 gallon, 4-foot maximum depth concrete-lined ponds; and an unlined 250,000-gallon, 10-foot deep simulated lake.

During the initial stages of the pilot program, several batch test evaluations of the treated water were conducted in 1200-gallon rubber tanks. Alum and lime were used in several concentrations such that the product water contained between 1 and 5 mg./l. phosphate. Extensive regrowth occurred in each case within two months. Concentrations of *Chlorella* and *Ankistrodesmus* reached 600,000 cells/ml.

In another experiment, phosphate was reduced to 0.2 mg./l. with 300 mg./l. of alum, and the water divided between two 1200-gallon tanks. Dipotassium phosphate was added to one tank to raise the phosphate concentration to 56 mg./l. Regrowth of algae was greatly retarded in the low phosphate water although, after six weeks, both test basins had similar cell counts, turbidity, and appearance.

The high phosphate water produced a great deal more algae in the same time period and accumulated a significant sludge deposit of dead algae on the tank bottom. This test indicated that phosphate reduction would not necessarily influence the actual concentrations of algae to be expected in the recreational lakes but that rates of algae production would be significantly inhibited. As a consequence there should be fewer maintenance problems in the lake due to sludge accumulations and the lake environment should be more suitable for fish.

Draw and fill tests

A long-term experiment consisted of adding alum-treated water with low turbidity and phosphate to the 10,000-gallon pond to maintain about a 40-day detention period. All of the water was filtered and some of it chlorinated. Alum doses varied between 200 and 300 mg./l. (Eight months' data are averaged in Table 2 for the period between November 1964 and June 1965.) Generally pH values, which were between 6.5 and 7.5 for the treated water entering the basin, rose to pH 9 and phosphate was within the 2 mg./l. maximum phosphate quality criterion initially set. The pH rise probably resulted from algae fixing CO_3 and HCO_3 from the water. The water also contained COD and algae concentrations similar to or greater than Pond 3. The dissolved oxygen concentration never reached the intolerably low values observed in Pond 3.

Several other proposed methods of controlling algae regrowth were tested. Lampblack and powdered activated carbon were used without success. In theory, the carbon would adsorb sunlight and prevent light penetration to the algae. However, the carbon failed to stay suspended in the water for more than a few days and no growth inhibition was noticed.

Crustaceans were placed in the water and on two occasions, when the pH was lowered with acid to pH 7, blooms of rotifiers and crustaceans consumed nearly all the algae. However, the crustaceans died and algae growth eventually resumed. Chlorination up to 10 mg./l. is not effective in reducing algae concentrations for more than a few days. Organic algicides and copper compounds controlled certain algae species but they were not effective for all types of algae. Furthermore, they are not effective for any significant time when used at concentrations that would not be harmful to fish.

All of these studies were conducted during the pilot process evaluations when it was still uncertain whether phosphate control could be used to prevent objectional algae growths in the recreational lakes.

Pilot plant operation

In July 1965, the pilot plant began operating continuously and at higher alum dosages. (Chemical data for the 10,000-gallon concrete-lined basin are summarized in Table 2 for the period between September 1965 and April 1966.) Use of 300 mg./l. of alum reduced phosphate residuals to one fifth and algae counts to between one third and one fourth. The predominant algae genera at times changed from the typical green algae usually associated with polluted water (*Scenedesmus*, *Closteridium*, and the like) to *Nannochloris coccoides Naumann*, very small green algae that have rarely, if ever, been observed in polluted water.

The effect of low phosphate residuals was even more striking in the 250,000 gallon unlined basin (chemical and algae data are shown in Table 2). *Nannochloris coccoides Naumann* was the most

prominent and often the only algae genus observed. Because of the extremely small size of *Nannochloris coccoides*, algae counts in the basin did not equal the weight of organic matter in oxidation Pond 3, which averaged about 200,000 counts/ml. The dissolved oxygen levels in this and the smaller 10,000-gallon basin were at least 5 mg./l. or more throughout a year of operation, and the diurnal dissolved oxygen changes were minor compared to those in Pond 3.

Algae will strip most of the remaining orthophosphate from tertiary effluent. Total phosphate concentrations entering the basins averaged 0.25 to 0.3 mg./l., but concentrations in the lakes stayed below 0.05 mg./l. Algae used the phosphate, then settled to the bottom where the phosphate was unavailable. However, extensive decomposition of the sludge layer might cause a sharp increase in phosphate concentration. Low phosphate concentrations (<0.5 mg./l.) limited growth in both holding basins during the continuous pilot plant preferred process studies in which approximately 300 mg./l. alum was used.

Laboratory studies were also conducted to determine if the reduction in phosphate in the pilot plant was in fact inhibiting algae growth. Samples of product water were injected with varying concentrations of phosphate and of other micronutrients (usually Hutner's micronutrient solutions[a]) known to be essential for algae growth. The samples were exposed to continuous fluorescent lighting and stirred with a wrist-action shaker. The tests showed that:

- Some algae growth occurred at phosphate concentrations as low as 0.05 mg./l.
- Phosphate concentrations of 0.1 to 0.3 mg./l. significantly inhibited the rate and density of algae growth.
- Phosphate concentrations below 0.5 mg./l. inhibited algae growth.
- Phosphate concentrations between 1 and 30 mg./l. supported about the same amount of algae growth.

To inhibit algae growth entirely would probably require removal of phosphate to concentrations well below 0.05 mg./l. in the product water. Such removal is economically unfeasible and appears unnecessary because of the apparent suitability of the treated water for the recreational lakes.

[a] Hutner's micronutrient solution: The complete solution added 0.76 mg./l. zinc, 0.2 mg./l. boron, 0.14 mg./l. manganese, 0.03 mg./l. iron, 0.04 mg./l. copper, 0.06 mg./l. molybdenum, and 1.75 mg./l. EDTA (ethylenediaminetetraacetic acid). Other solutions with one or more nutrients left out were also used.

TABLE 1

Comparison of Pond 3 and processed water characteristics

Characteristics	Pond 3 water	Product water
pH	8.3	6.7
Turbidity (JTU)	90	4
Total alkalinity (mg./l. as $CaCO_3$)	260	95
Hardness (mg./l. as $CaCO_3$)	80	100
Suspended solids (mg./l.)	75	6
Dissolved solids (mg./l.)	575	575
Chemical oxygen demand (mg./l.)	250	50
Biological oxygen demand (mg./l.)	38	<10
Dissolved oxygen (mg./l.)	0.1–40	7–15
Ammonia–N (mg./l.)	0.1–20	0.1–20
Organic–N (mg./l.)	7–20	1–3
Nitrate–N (mg./l.)	1–4	1–4
Nitrite–N (mg./l.)	0.1–12	0.1–12
Total nitrogen (mg./l.)	7–20	3–20
ABS (mg./l.)	3	3
Phosphate (mg./l.)	40	0.25
Algae (counts/ml.)	200,000	7,000
Confirmed coliform (MPN/100 ml.)	7,900	<1.8
Chlorine residual (mg./l.)	—	0.2–0.5
Sulfate (mg./l.)	60	240

TABLE 2

Comparison of water characteristics in holding basins

Observation period	Water temperature (° C.)	pH	Phosphate (mg./l.)	Algae counts (thousands per ml.)	Predominant algae genera
10,000-gallon holding basin					
Pilot plant process evaluation Nov. 1964–June 1965	11	9.0	0.73	926	Closteridium and Scenedesmus
Continuous pilot plant evaluation Sept. 1965–Apr. 1966	13	8.9	0.12	247	Oscillatoria, Scenedesmus, Nitzschia, and Nannochloris coccoides
250,000-gallon holding basin Sept. 1965–Apr. 1966	15	8.8	<0.05	~2400	Nannochloris coccoides

Fish survival tests

Approximately 125 game fish (25 bass, 50 bluegill, and 50 catfish) were placed in the 10,000-gallon and 250,000-gallon basins for observation. Some 700 Gambusia or mosquito fish and 20 fathead minnows were also added to provide food for the larger game fish. About 90% of the fish are still active in the ponds. A few fish were lost on four different occasions because of specific, but unrelated, causes.

Several fish died when the chlorine residual increased from 0.2 to 1.5 mg./l. in the 250,000-gallon basin. Rising ammonia concentrations in December had eliminated free chlorine residuals and the dosage was increased to 12 to 15 mg./l. to maintain bactericidal control with the less effective

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chloramines. The chloramines were so stable, however, that they were not utilized by other organics in the large holding basin. Reduction of the chlorine dose resulted in recovery of the remaining fish.

Again during the colder season, another effect of high ammonia concentrations was observed when the ammonia reached 8 mg./l. and the fish began to exhibit signs of distress. The high ammonia concentration coincided with a rise in pH apparently related to increased algal activity as water temperatures were also climbing.

At higher pH values, the percentage of ammonia in the form of ammonium hydroxide increases substantially and apparently becomes a toxic agent to fish. This problem can be circumvented in the proposed 0.5-m.g.d. tertiary treatment plant by selective storage and withdrawal of water low in ammonia. The ammonia entering the oxidation ponds is readily converted to other nitrogen compounds during periods of warm weather. With an average detention time of 45 to 60 days between the inlet of the oxidation ponds and the point of withdrawal to the tertiary process, ammonia levels do not rise substantially in Pond 3 until some time around December. By April, rising water temperatures cause a sudden drop in ammonia concentrations throughout the oxidation ponds. By filling oxidation Pond 3 to capacity prior to the rise in ammonia concentrations and then bypassing around it during the winter, there will be low ammonia content water for the recreational lakes throughout the year.

During the latter part of the cold season in 1966, the dissolved oxygen level fell below 3.5 mg./l. throughout the 250,000-gallon simulated lake. The water had a brownish appearance and algae counts decreased to 50,000 cells/ml. Some fish were in distress. Artificial aeration was provided and the dissolved oxygen level increased to saturation within three days. The brownish color was probably caused by a bacterial bloom that used up more oxygen than was being produced by the few algae present.

This experience emphasized that any biological system is subject to unpredictable changes and that blooms of bacteria, crustaceans, or algae may result in occasional oxygen depletion in any recreational lake using reclaimed water. Some method for supplementing the oxygen content of recreation lake water should, therefore, be provided for emergency use.

Conclusions

Turbidity, algae, and phosphate reduction of conventional oxidation pond water can be economically achieved. A practical tertiary process has been developed to supply boating and fishing lakes near Lancaster, Calif. The process selected and piloted at 30 g.p.m. features treatment with 200 to 300 mg./l. of alum, sedimentation, filtration, and chlorination. Phosphate is consistently reduced from 40 mg./l. to less than 0.5 mg./l. and algae counts from several hundred thousand to a few thousand per milliliter. Product water has been evaluated in the laboratory and in large simulated lakes stocked with fish. Algae slowly grow to high concentrations in the water but the rate of biological activity does not deplete the oxygen supply, or interfere with fish life, or cause nuisances. Laboratory stimulated growth tests show that algae growth rates are inhibited at phosphate concentrations less than 0.5 mg./l. and almost stop at less than 0.05 mg./l. The ecology of the simulated lake is typical of a fresh water environment supplied with limited nutrients.

ADDITIONAL READING

Cohen, J. M., "Improved Jar Test Procedure," *J. Am. Water Works Assoc.* **49** (11), pp. 1425–31 (1957).

Malhotra, S. K., *et al.*, "Nutrient Removal from Secondary Effluents by Alum Flocculation and Lime Precipitation," *Intern. J. Air-Water Pollution* **8,** 487–500 (1964).

Merrell, J. C., Jr., and Katko, A., "Reclaimed Waste Water for Santee Recreational Lake," *Calif. Water Pollution Control Assoc. Bull.* **2** (3), 10–15 (Jan. 7, 1966).

Sawyer, C. N., "Fertilization of Lakes by Agricultural and Urban Drainage," *J. New Engl. Water Works Assoc.* **61,** 109–127 (1947).

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